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SKY & TELESCOPE

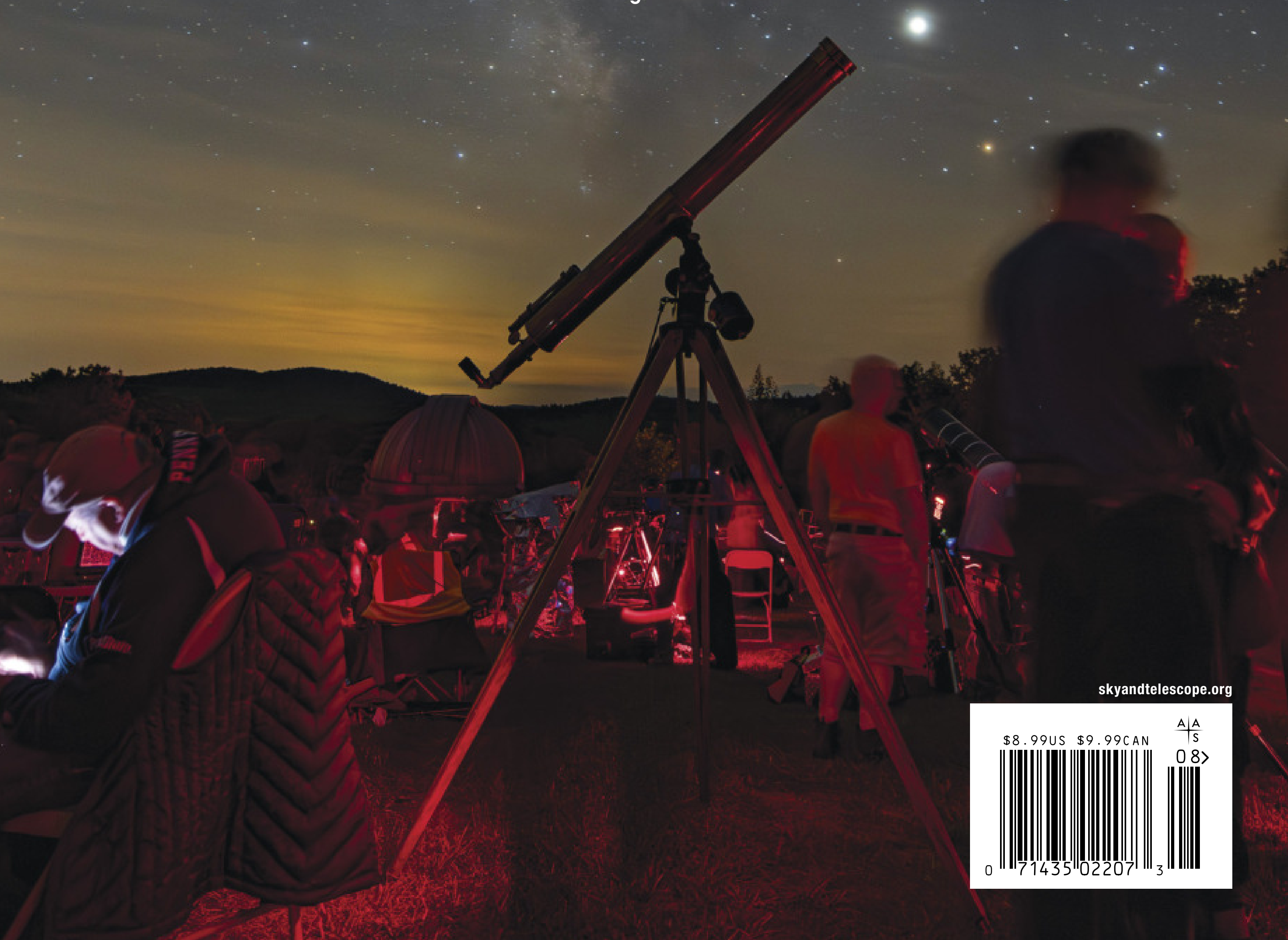
THE ESSENTIAL GUIDE TO ASTRONOMY

AUGUST 2023

Stellafane

100 Years on Breezy Hill

Page 60



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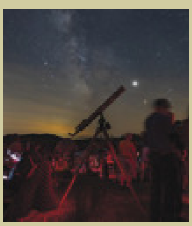

A brass-tube 4-inch refractor at the 2019 Stellafane Convention

PHOTO: DENNIS DI CICCO

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The Big Draw

MOUNTAINEERS HAVE EVEREST. Buddhists revere Mount Kailash. For amateur telescope makers (ATMs), the most sacred summit of all is Breezy Hill. Every summer, this modest hillock outside rural Springfield, Vermont entices ATMs and astronomy enthusiasts from far and wide for the annual Stellafane Convention.

Since its founding in 1923, the Springfield Telescope Makers and their pink-painted clubhouse atop Breezy Hill have been the center of gravity for the ATM movement. (The convention itself began in 1926.) As Dennis di Cicco explains in our cover story on page 60, a key early visitor from afar was *Scientific American* editor Albert Ingalls, who came up from New York in 1925. Ingalls, Dennis says, "played a huge role in getting the hobby launched in this country."

Ever since, except for one or two hiatuses, Breezy Hill has annually attracted visitors from across the country and beyond. Amateurs have arrived from as far as Europe, Japan, and Australia. Many wouldn't miss a convention. Dennis himself has come every year since 1967 save one, 2008, when he was busy co-leading an *S&T* eclipse tour in China. *S&T*'s editorial assistant, Sabrina Garvin, has joined her grandfather there every year since she was a toddler. Children, of course, are a delightful hallmark of this family affair.

▲ Gravitational pull: the Stellafane Convention in 1985

COURTESY OF DENNIS DI CICCO

The Convention has welcomed many luminaries, from Apollo 12 astronaut Alan Bean to Pluto discoverer Clyde Tombaugh. For Dennis, who drove up for his first visit at age 17 soon after getting his driver's license, one especially memorable early attendee was the late George Keene. Dennis had become smitten with astrophotography, and Keene's *Star Gazing with Telescope and Camera* was one of only two books the teenager then owned on the subject.

Another well-known personality who visited Stellafane regularly, especially in his later years, was John Dobson, father of the Dobsonian telescope. Other scope builders, such as Tele Vue's Al Nagler and Astro Physics' Roland Christen, have tested prototypes at Stellafane that later evolved into commercial products. Many amateurs got their first taste of early Go To telescopes at the event.

Still, the real gravitational pull has always been the people. When I asked Dennis what was the most lasting connection he'd developed out of his 50-plus annual visits to Breezy Hill, he responded, "It's everybody that you see every year, and that you *only* see at Stellafane. These are enduring friendships that will last forever."

All of us at *S&T* wish the Springfield Telescope Makers the best with their centennial celebration. We look forward to seeing everyone this August 17–20 up on Breezy Hill.

Peter

Editor in Chief

SKY&TELESCOPE
The Essential Guide to Astronomy

Founded in 1941 by Charles A. Federer, Jr. and Helen Spence Federer

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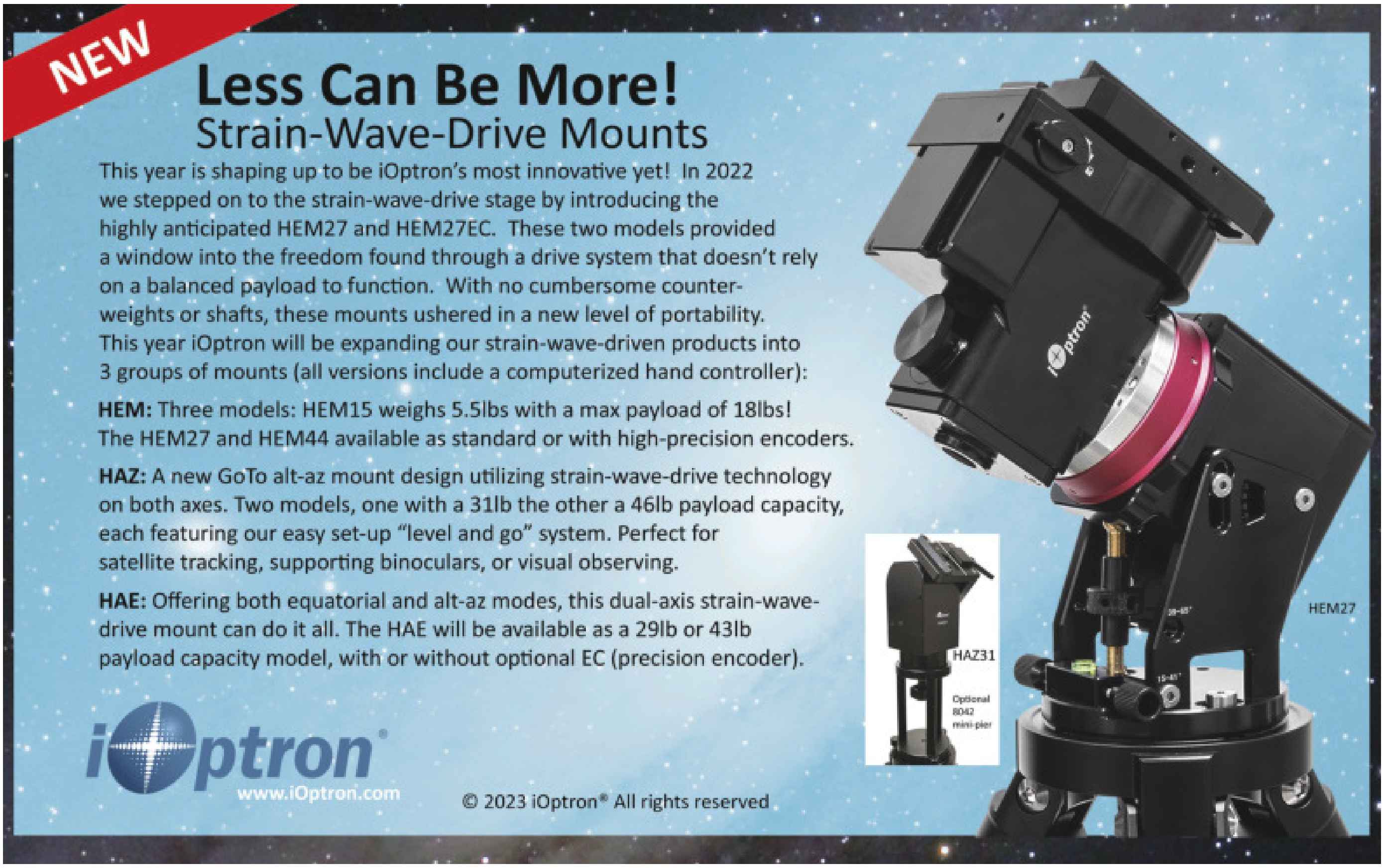
NEW
Less Can Be More!
Strain-Wave-Drive Mounts
This year is shaping up to be iOptron's most innovative yet! In 2022 we stepped on to the strain-wave-drive stage by introducing the highly anticipated HEM27 and HEM27EC. These two models provided a window into the freedom found through a drive system that doesn't rely on a balanced payload to function. With no cumbersome counter-weights or shafts, these mounts ushered in a new level of portability. This year iOptron will be expanding our strain-wave-driven products into 3 groups of mounts (all versions include a computerized hand controller):
HEM: Three models: HEM15 weighs 5.5lbs with a max payload of 18lbs! The HEM27 and HEM44 available as standard or with high-precision encoders.
HAZ: A new GoTo alt-az mount design utilizing strain-wave-drive technology on both axes. Two models, one with a 31lb the other a 46lb payload capacity, each featuring our easy set-up "level and go" system. Perfect for satellite tracking, supporting binoculars, or visual observing.
HAE: Offering both equatorial and alt-az modes, this dual-axis strain-wave-drive mount can do it all. The HAE will be available as a 29lb or 43lb payload capacity model, with or without optional EC (precision encoder).
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Optional 8042 mini-pier
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◀ Julian Samuel drew this sketch of the Andromeda Galaxy (M31).

Binoviewers and Dark Skies

Howard Banich's "The Great Edge-On Galaxy of Spring" (*S&T:* May 2023, p. 20) is beautifully written. I always read his articles with a star atlas.

I started amateur astronomy three years ago. I live under a Bortle 9 sky in Toronto, Canada, but we do sometimes get clear nights. I use a 254-mm (10-inch) reflector telescope, but I also observe with an Orion Premium Linear BinoViewer with 20-mm Plössls, 18.2-mm DeLites, and 9-mm eyepieces. I find these work well.

I read somewhere that Banich also uses a binoviewer. Would he be kind enough to let me know what sort of binoviewer he has and what eyepieces he prefers?

Banich's sketches on pages 22 and 23 are elegant and vast. Does he sketch on black paper?

Thank you very much for such inspirational writing.

Julian Samuel
Toronto, Canada

Howard Banich replies: *Wow, I like the abstract quality to your Andromeda Galaxy piece. Well done!*

I had a Denkmeier Optical Deepsky Binoviewer for many years, but I rarely used it and finally sold it a few months ago. I used 24-mm Panoptic and 10-mm Radian eyepieces, which worked well with my old 28-inch f/4 scope.

And thank you, I always appreciate positive feedback on my articles and sketches. I use white paper and 0.7-mm HB lead in a mechanical pencil to sketch, then scan the image into GIMP (GNU Image Manipulation Program). There, I invert the sketch into a positive image with a black background and grayscale sketch. I haven't tried black paper yet, but I'm sure I will at some point just to see what it's like!

Congratulations on a superb article in the May issue of *S&T*! It's great to see some extreme challenges in the magazine (the distant companion galaxies). Banich's sketches (in this article and in previous ones) are as realistic as any I've seen in print.

Where is the Oregon campground at which he was able to extract consistent Sky Quality Meter (SQM) readings of 22.00+? I've been trying to coax a number of my fellow end-of-active-service troops to go on a trip to Massacre Rim Dark Sky Sanctuary (Nevada) later this year, but they're balking at the rustic remoteness of the place. I might be willing to meet them halfway on a compromise if I can convince them that 22.00 skies are something too good to pass up. ☺

Andy Edelen
Eugene, Oregon

Howard Banich replies: *I really appreciate that you liked the article and sketches enough to let me know. As for the campground I've been going to, it's Chickahominy Recreation Site, which is about 30 miles (51 km) west of Burns, Oregon, right off U.S. Highway 20.*

It's not a perfect site. Headlights from the highway can be bothersome, and there's a small light dome in the east from Burns. Plus, I've been there enough times to know that 22.00+ SQM nights are in the minority — I usually see readings in the 21.70 range. Nothing to sneeze at, but a long way from 22.00+. It's all about the transparency, of course. When it's really good, the light dome from Burns disappears. All this makes Chickahominy much like many sites in central and eastern Oregon.

It has the advantage of being easy to drive to, though. Google Maps indicates a 4-hour-and-6-minute drive from Eugene, Oregon. Chickahominy does have excellent cell service, though. For example, I was able to join a Zoom meeting from there once.

It's a mixed bag, but if you hit on the right nights, you'll never forget the skies.

Martian Inspiration

William Sheehan's Focal Point essay "Seeking Canals on Mars" (*S&T:* May 2023, p. 84) caught me at an opportune time. Just a week before reading it, I acquired a reprint of Percival Lowell's book *Mars and Its Canals* and was reliving the memory of reading the book as a kid in the late '50s. That book fed interests that inspired my later career in engineering and science, and astronomy remained a lifelong hobby.

Though Lowell described his book on Martian canals as "popular science," there was no mistaking that his 24-inch refractor was a serious instrument being put to astronomical use. New data overtook his theories, but what impressed me then was his dedication to his research and his skill at communicating it.

Today, Lowell certainly deserves some degree of credit for inspiring the mobile laboratories now roaming the surface of Mars measuring its minute physical properties. And for the little helicopter sending back pictures of where the canals were thought to be.

Jeff G. Bohn
Malvern, Pennsylvania

An Army of Exoplanets

An impressive roster of ever more advanced space telescopes are revealing multitudes of exoplanets, as described in Knicole Colón's "Exoplanets Everywhere"

(*S&T:* May 2023, p. 34). I noted that the planets' orbital alignment must be just so for astronomers to detect them.

It's hard to fathom that so many star systems are exquistely aligned for detecting planetary transits. How can so many of them be lined up so perfectly? Perhaps they are arranged that way from being part of the Milky Way? Can one speculate on what proportion of stars not properly aligned for planetary detection could harbor planets?

Robert Pellenbarg
Berlin, Maryland

Monica Young replies: *It is statistically unlikely for a planet to be transiting its star from our perspective. How likely it is depends on a number of factors, including the size of the star, the size of the planet, how close the planet is to its star, and the distance of the star from Earth. Such calculations have been done for the larger population of planets in the Milky Way, and those estimates say that for every transiting planet we see, there are 10 or maybe even 100 more. If you're only looking at close-in planets, the likelihood of catching transits is higher, with every transiting planet standing in for two or three that are not.*

Applause For Emily

I want to compliment the editors of *S&T* regarding two superb articles written by Emily Lakdawalla: "Rock On" (*S&T:* Feb. 2022, p. 12) and "Venus Renaissance" (*S&T:* May 2022, p. 12). I'm not in the habit of writing to magazines regarding articles I've read, but I feel it is my duty to give you feedback on a job well done.

I've been a highly satisfied subscriber to *S&T* for many years. I initially noticed the outstanding input of Emily Lakdawalla from her articles in *The Planetary Report* magazine. Aware that she was amongst the contributing editors of *S&T*, I took special interest in her February and May 2022 contributions and was pleased to find that both articles are further examples of her outstanding science-writing skill. I'm therefore hopeful that you're aware of the treasure you have amongst your authors, and I look forward to more of her insight and brilliant features.

Martin Lee Collin
Tel Aviv, Israel

FOR THE RECORD

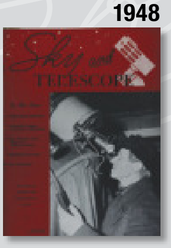
• Although Ulugh Beg's star catalog was a significant improvement on Ptolemy's, its average accuracy was nowhere near as good as that of Tycho Brahe's star catalog, unlike what was stated in "The Past and Future of Star Names" (*S&T:* May 2023, p. 26).

• In April's Sky at a Glance (*S&T:* Apr. 2023, p. 41), the new Moon occurred at 4:13 UT on April 20th.

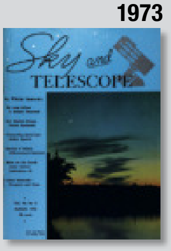
SUBMISSIONS: Write to *Sky & Telescope*, 1374 Massachusetts Ave., 4th Floor, Cambridge, MA 02138, USA, or email: letters@skyandtelescope.org. Please limit your comments to 250 words; letters may be edited for brevity and clarity.

75, 50 & 25 YEARS AGO by Roger W. Sinnott

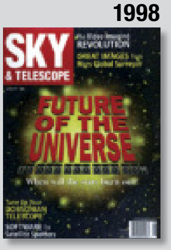
1948



1973



1998



◖August 1948

Poor Reception "Radio engineers have noted that three or four days after new or full moon the usable bands of frequencies for short-wave broadcasts to distant stations are slightly narrower than at other times. This effect has been associated with the tide-producing action of the moon on the ionospheric layers of the earth's atmosphere. . . . The sun first plays its role by ionizing the atmosphere on the earth's sunlit side. Currents flow in this ionized atmosphere, and are modified by the tidal effects of the moon. This tends to lessen the ion density, thereby reducing the highest frequency that can be used for broadcasts."

◖August 1973

Before ISS "Thousands of persons [on May 14th] viewed the historic launch of the American space station, Skylab . . . From the observer's viewpoint, however, the Skylab spectacular became most exciting eight hours later . . .

"David Shipano tells the story: 'Joe Steed and I [went to the Fernbank Science Center, Atlanta.] At about 9:42 p.m. EDT a bright object was seen about 60° high in Leo . . . Well, so much for Skylab, I thought.

"'Suddenly, someone shouted, 'Hey, there's another one!' At the place where the first object had appeared, I saw not one but two traveling together, about three degrees apart. Then came No. 4, followed by another pair. In all, the Fernbank observers saw seven bodies, of which No. 4 turned out to be the space laboratory itself. The first was [the Saturn rocket] second stage, the last the meteoroid shield that had torn loose, and the other four were parts of the nose-cone protective shroud. To put it mildly, we had seen some show!'"

◖August 1998

The End "Our society is steeped in the uneasy awareness that human extinction is possible. Nuclear Armageddon, ecological catastrophes, and mutant viruses are among the near-term doomsday prospects thrust forward by the prudent, the paranoid, and the profit-minded. In the longer run we fear such astronomical events as asteroid or comet impacts and galactic gamma-ray bursts. . . . But can life outlast the stars themselves? . . .

"Whether life can exist indefinitely, or whether the universe is structured to guarantee the final annihilation of all consciousness, purpose, and meaning — including any record . . . — holds an inordinate fascination."

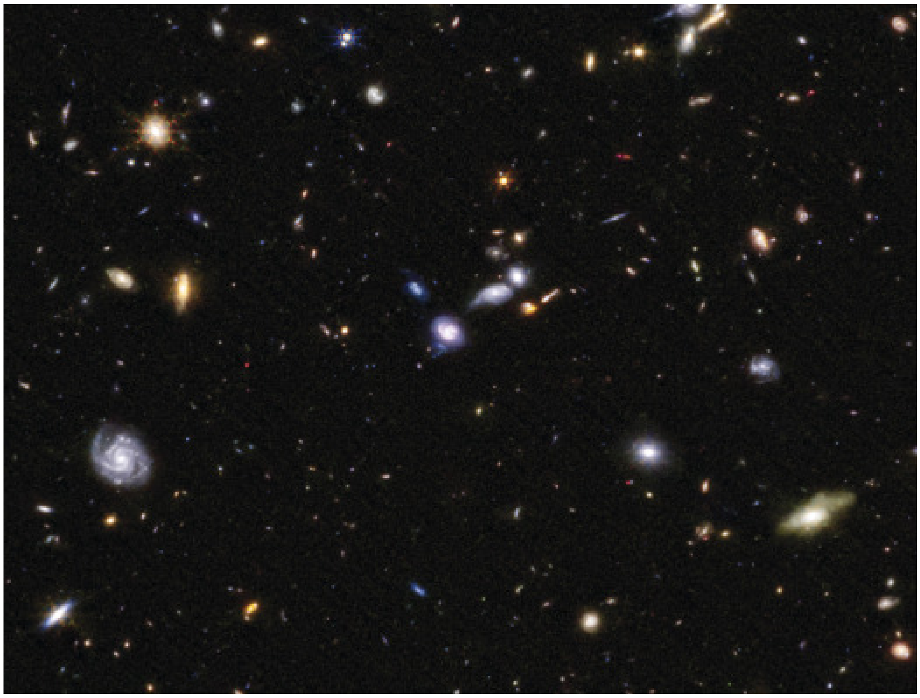
So astrophysicists Fred Adams and Gregory Laughlin conclude their peek into the far future, having taken us through what they call the Stelliferous Era (the present), the Degenerate Era (100 trillion years to come, when all stars are dead), the Black Hole Era (perhaps 10^{37} years ahead), and beyond. Classics like this article are a good reason to save your back issues!

COSMOLOGY

What We Can Learn from Massive Early Galaxies

ASTRONOMERS HAVE USED the James Webb Space Telescope (JWST) to reveal a host of high-mass galaxies in the early universe — but according to a new study, they shouldn't really exist. Either astronomers have misunderstood something about the galaxies themselves, or our leading model of cosmology should be called into question.

JWST has provided unprecedented views of the universe in the first few hundred million years after the Big Bang, revealing surprisingly large, star-



▶ JWST's Near-Infrared Camera revealed early galaxies in the region of sky originally covered in the Hubble Ultra Deep Field.

EXOPLANETS

TRAPPIST-1b Has No Atmosphere

SEVEN PLANETS CIRCLING a red dwarf star 40 light-years away might offer one of our best shots at observing potentially habitable worlds. But the innermost planet, TRAPPIST-1b, has shown its true colors to the James Webb Space Telescope (JWST): Astronomers already knew it was located too close to the star to be habitable, but new observations reveal that TRAPPIST-1b is too hot to even have an atmosphere.

Thomas Greene (NASA Ames Research Center) and colleagues report March 27th in *Nature* a series of observations that caught the planet as it passed behind its star from our point of view. During five such *secondary eclipses*, JWST measured light both from the star itself and from starlight reflected off the planet's dayside, giving a measure of the planet's temperature: between 480 and 530 kelvin (400 to 500°F).

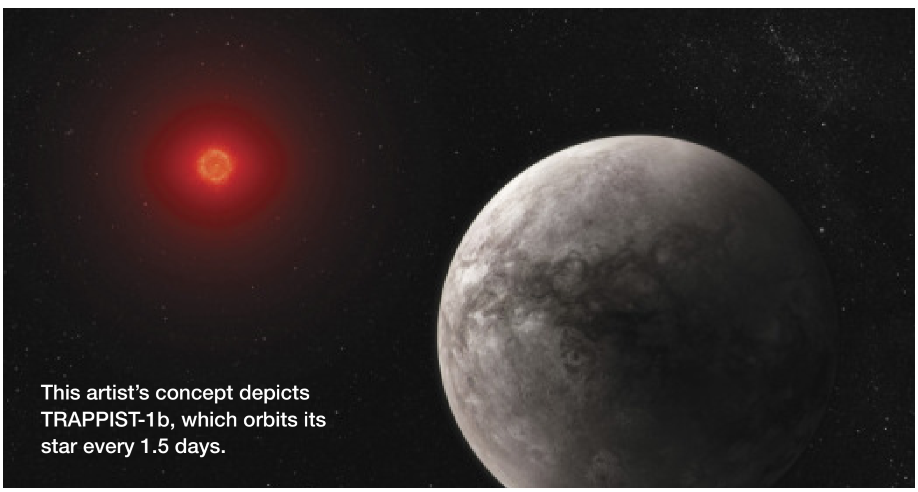
Astronomers had expected the planet to be hot; even with an atmosphere, the surface would be around 400K. But the hotter temperature that JWST measured matches that of an airless world, one without winds to redistribute heat. (For comparison, Mercury's surface is even hotter, around 700K.)

Besides having no atmosphere, the planet appears to reflect hardly any light. Greene and colleagues note that there's still plenty of wiggle room for surface composition, which could contain minerals such as anorthite, basalt, enstatite, feldspar olivine, pyroxene, quartz, or saponite.

It's unclear what this bodes for TRAPPIST-1's other planets, especially TRAPPIST-1e, f, and g. These three worlds are hypothetically habitable — but only if the red dwarf star's active youth didn't strip them of their atmospheres long ago. Besides producing powerful ultraviolet and X-ray flares, stars like TRAPPIST-1 are also brighter in their youth for a period of a billion years or so. Planets now in the habitable zone might once have been too close and hot for water to survive.

Observations of TRAPPIST-1's other worlds are already in the works. As astronomers work their way outward, we'll find out just how habitable this star's habitable zone might be.

■ MONICA YOUNG



This artist's concept depicts TRAPPIST-1b, which orbits its star every 1.5 days.

DEEP FIELD: NASA / ESA / CSA / STSCI / C. WILLIAMS (NSF'S NOIRLAB) / S. TACCHELLA (CAMBRIDGE) / M. MASEDA (UW-MADISON), IMAGE PROCESSING: J. DEPASQUALE (STSCI); PLANET AROUND RED DWARF: NASA / ESA / CSA / J. OLMSTED (STSCI)

filled galaxies early on (*S&T:* May 2023, p. 9). Michael Boylan-Kolchin (The University of Texas at Austin) investigated this finding, publishing his results April 13th in *Nature Astronomy*.

According to the leading cosmological model, ordinary matter mixed with dark matter in the early universe. So when dark matter gravitationally collapsed, mixed-in ordinary matter followed, forming the first stars in early galaxies. Boylan-Kolchin calculated how much ordinary matter would need to end up in stars to account for the most massive of these galaxies. "Almost every available atom would have been used to make stars," he says.

Star formation approaching 100% efficiency would be borderline impossible, Boylan-Kolchin says. "It's more like 10% in the modern universe."

"The theoretical analysis in this paper is very sound," says Mark Vogelsberger (MIT), who was not involved in the research. "There are not many assumptions going into the calculation, which renders the results very robust."

But Boylan-Kolchin isn't ready to dispense with standard cosmology just yet. "No other theory can do what it does — it would be a last resort to overthrow it," he says.

Another study, published in the April 13th *Science,* might give a hint: A team led by Hayley Williams (University of Minnesota) announced the discovery of an intriguing galaxy 500 million years after the Big Bang, also using JWST. Williams found that the galaxy has a star-formation rate tens of times higher than galaxies 150 million years later.

"This galaxy has a much lower mass than the galaxies discussed [by Boylan-Kolchin] but, if this kind of star formation can also happen in higher-mass galaxies at similar redshifts, it could help explain the tension with the standard cosmological model," she says.

Boylan-Kolchin isn't so sure, because this object is just 105 light-years across — it might be a globular cluster rather than a galaxy. Instead, he thinks a likely scenario is that some of the early galaxies' light might be coming not from stars but from accretion disks around supermassive black holes.

Additional data, both in the form of larger statistical surveys as well as spectroscopic follow-up to confirm galaxies' distances, will help ascertain whether the tension between observations and standard cosmology holds up. "We really should know if this a serious problem within a couple of years, maybe less," Boylan-Kolchin says.

■ **COLIN STUART**

SOLAR SYSTEM

85,000 Volcanoes Mapped on Venus

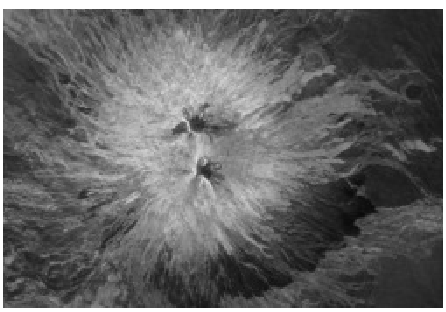
A NEW CATALOG pinpoints thousands of volcanoes in Magellan's radar images of Venus. Graduate student Rebecca Hahn (Washington University in St. Louis) spent two years poring over this imagery, manually mapping every volcano. Hahn and Paul Byrne (also at Washington University in St. Louis) describe the work in the April *Journal of Geophysical Research: Planets*. The result is the most detailed and complete map of Venusian volcanoes ever made.

The new catalog lists the size and location of some 85,000 individual volcanoes, 50 times more than the most complete previous catalog. "The complete data set, with locations of all volcanoes and planforms of the larger volcanoes, will be immensely useful both for mission planning and for future research on Venus volcanism and its relationship to interior processes," says Robert Herrick (University of Alaska Fairbanks). Herrick recently found the first clear sign of active volcanism within the same set of Magellan images (*S&T:* July 2023, p. 8) but wasn't involved with the new study.

Volcanoes less than 5 kilometers (3 miles) in diameter make up about 99% of the catalog, while the bigger volcanoes are likely to be either less than 20 km in diameter or more than 100 km across, with few in-between. Large volcanoes also seem to cluster toward the equator, with none at the south pole and relatively few near the north pole. However, the map reveals no volcanic clusters or chains, as seen on Earth due to plate tectonics. "They seem to be all over the place," Byrne says.

Hahn and Byrne have made their map publicly available for other researchers to use, and other analyses are ongoing.

■ **JAVIER BARBUZANO**



NASA / JPL

▶ Sapas Mons, a large volcano on Venus, is about 400 km (250 miles) in diameter.

IN BRIEF

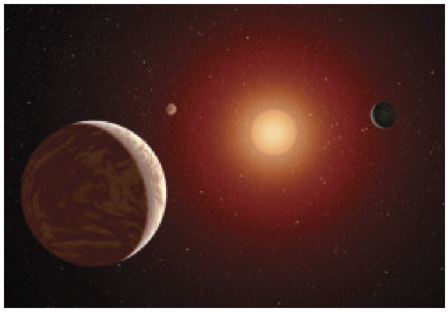
Broadcasting the 2024 Total Solar Eclipse

The Dynamic Eclipse Broadcast Initiative is a citizen-science project that aims to broadcast the April 8, 2024, total solar eclipse online, while also recording images of the solar corona for later scientific analysis. Plans include several dozen observing sites within the path of totality from which teams will collect data, as was done in 2017. These data will allow astronomers to measure the velocity and acceleration of material in the inner corona. However, the group is planning something different for the 2024 eclipse, including dozens of observing sites *outside* the path of totality that will also play an important role. Simultaneous observations from locations both inside and outside of totality will enable a detailed cross-section, including all of the different regions of the Sun's atmosphere — beginning at the visible surface and running all the way out to a distance of several solar radii. To learn more and get involved, visit **debinitiative.org**. The team has been working to test an improved equipment package for all sites to use, and training is included.

■ **ZACK STOCKBRIDGE**

EXOPLANETS

Giant Planets Around Small Stars



▲ Three giant planets surround a red dwarf star in this artist's concept.

IN 2019 ASTRONOMERS found something strange — a gas giant orbiting a star with only a tenth the mass of the Sun, an *M* dwarf dubbed GJ 3512. The discovery was an anomaly, because there shouldn't have been enough material around the star to form such a big planet in the first place.

Now, in the May *Monthly Notices of the Royal Astronomical Society*, Edward Bryant (University College London) and collaborators have identified other possible gas giants orbiting low-mass stars. The 2019 discovery, it appears, is not unique and instead calls standard planet-formation theories into question.

In the *core accretion* scenario, planetesimals first collide and stick together, becoming rocky cores the size of a few Earth masses, then they start to gather large amounts of gas around themselves. This theory works well in simulations of most star systems, including our own. But small stars host similarly low-mass planet-forming disks, and the lowest-mass stars shouldn't make giant planets via core accretion at all.

Astronomers have proposed several ideas to explain the existence of GJ 3512b. Maybe the planet wandered in, or maybe it collapsed together more suddenly via *disk instability*.

Bryant's group, however, showed that singular explanations aren't enough. When they analyzed data from the Transiting Exoplanet Survey Satellite, including more than 91,000 low-mass stars, they identified 15 with transiting giant-planet candidates. They calculate that only 0.1% of stars with less than half the Sun's mass host giant planets, a low rate that is nonetheless greater than the null rate astronomers had previously predicted.

Core-accretion and disk-instability models could potentially produce giant planets around even very low-mass stars under certain conditions, Bryant says. Or, he speculates, "maybe there is a third formation method going on that we don't know about yet."

Ultimately, astronomers will need more data on planetary systems in different stages of evolution to sort out this conundrum.

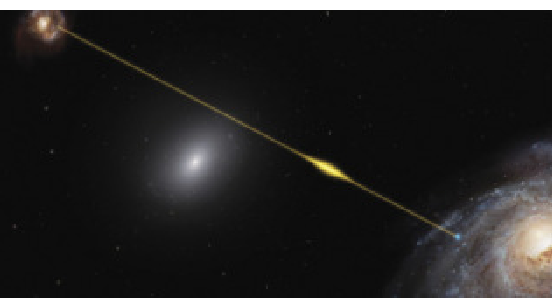
■ ARWEN RIMMER

GALAXIES

Radio Bursts Open View into Galaxy Halos

DISTANT FLASHES OF radio waves are helping astronomers learn about the hot gas that surrounds the Milky Way and other nearby galaxies.

Fast radio bursts (FRBs; *S&T:* Sept. 2022, p. 26) are most likely energetic explosions on or near strongly magnetized neutron stars in faraway galaxies. The radio waves slow down ever so slightly as they interact with plasma between the distant explosion and Earth, with lower-frequency waves slowing more than those at higher frequencies. As a result, the bursts — which usually last a millisecond or so — are smeared out over time. This *dispersion measure* is larger if there is more intervening plasma. Astronomers thus use FRBs as beacons to shine through the tenuous ionized gas in between and around galaxies, which is almost impossible to observe directly.



◀ The radio signal from an FRB passes through the halo of an intervening galaxy in this artist's concept.

Using the Canadian Hydrogen Intensity Mapping Experiment (CHIME) telescope in British Columbia, Amanda Cook (University of Toronto) and a team of astronomers have conducted a detailed analysis of 93 FRBs, published in the April 1st *Astrophysical Journal*. They find that the halo of our own Milky Way contains less baryonic matter than most galaxy evolution models predict. The team's analysis confirms an earlier analysis of just one FRB, observed with the Deep Synoptic Array under construction in California. Vikram Ravi (Caltech), who presented the result at the January American Astronomical Society meeting, suggested that the Milky Way's halo might have lost baryonic matter over time via mechanisms such as supernova explosions and strong stellar winds.

Meanwhile, an international team led by Joeri van Leeuwen (ASTRON) has bagged five FRBs with the recently upgraded Westerbork Synthesis Radio Telescope in the Netherlands. As his team describes in the April 12th *Astronomy & Astrophysics*, three of the five Westerbork bursts occurred close to the Triangulum Galaxy (M33) on the sky. Their radio waves pierced the halo of this nearby spiral, as well as the extended halo of the closer Andromeda Galaxy (M31). In principle the bursts' dispersion measures could provide information on the halos of M33 and M31 as well as our own galaxy, but analysis is complicated.

In the near future, astronomers expect to pinpoint many more fast radio bursts, creating a network of FRB searchlights to reveal the distribution of ionized gas through space and time. "I'm won over," Van Leeuwen says. "FRB cosmology is the future."

■ GOVERT SCHILLING

SOLAR SYSTEM

Does Earth Have a New Quasi-Moon?

RECENTLY DISCOVERED asteroid 2023 FW_{13} turns out to be on a solar orbit that's in 1:1 resonance with Earth. So it circles our planet — albeit on an eccentric orbit that sweeps halfway out to Mars and halfway in to Venus.

There's no formal definition for such *quasi-moons*, though they generally follow a short-term path around Earth. Perhaps the best known of these objects is 469219 Kamoʻoalewa, found in 2016 (*S&T:* Oct. 2016, p. 10). Kamoʻoalewa's orbit will remain in resonance with Earth for centuries to come.

But the newfound asteroid could handily eclipse that record. Early estimates say it has circled Earth since at least 100 BC and will likely continue to do so until around AD 3700. If that's correct, 2023 FW_{13} would be the most stable quasi-moon ever found.

The asteroid, which is some 10 to 20 meters across (30 to 60 feet), was first observed March 28th by the Pan-STARRS observatory atop Haleakalā in Hawaiʻi. After further observations from the Canada France Hawaii Telescope on Mauna Kea, and from observatories on Kitt Peak and Mount Lemmon, the discovery was officially announced on April 1st.

Adrien Coffinet, a French astronomer and journalist, realized the asteroid's nature after running its orbital parameters through a simulator developed by Tony Dunn. By extrapolating the orbit into the past and future, the simulation led others to find pre-discovery observations dating back to 2012. The refined orbit confirms that not only is the asteroid a quasi-moon, but it has been so for millennia.

However, Alan Harris (Space Science Institute) cautions that, while 2023 FW_{13} does indeed circle Earth, it's not really a moon: "The dimension of the loop (about 0.18 astronomical unit in radius) is so large that Earth plays essentially no role in its motion," he says. For reference, Mercury orbits the Sun from 0.4 a.u. Yet, while the asteroid is not gravitationally bound to Earth, it's in gravitational resonance with our planet, which is why its path curves widely around us. Harris estimates there are a couple such objects currently looping around Earth.

■ DAVID L. CHANDLER

IN BRIEF

JUICE Launches for the Jupiter System

The European Space Agency's Jupiter Icy Moons Explorer (JUICE) lifted off on April 14th in a nominal launch that will ultimately take the spacecraft to the Jovian satellites. JUICE will take the long road to Jupiter, making one flyby past Venus in 2025 and three past Earth in 2024, 2026, and 2029 before arriving at Jupiter in 2031. JUICE also has the option to fly past the asteroid 223 Rosa in October 2029. Once in the Jovian system, JUICE will explore Ganymede, Europa, and Callisto via some 35 flybys in an effort to address questions on the moons' history and environment as well as the potential for habitability in their suspected internal oceans. The mission will end in orbit around Ganymede. Ten instruments aboard JUICE include high-resolution cameras as well as imaging and spectroscopy at wavelengths from ultraviolet to submillimeter. Other instruments include ice-penetrating radar, plasma sensors, and a laser altimeter. NASA's Europa Clipper, due to launch next year, will reach Jupiter just before JUICE, in 2030.

■ DAVID DICKINSON

Lunar Lander Crashes on the Moon

ISPACE

Hakuto R, a lunar lander built by the Tokyo-based company iSpace, fell silent right around the time it was heading for Atlas Crater on the Moon. While the spacecraft's final telemetry showed the lander in a vertical position on final approach, it also indicated that the descent speed was increasing rapidly in the final seconds. The company issued a statement acknowledging the loss, concluding, "There is a high probability that the lander eventually made a hard landing on the Moon's surface." Originally part of the Google Lunar X Prize competition, Hakuto R is the third lunar lander to crash on the Moon in recent years. Hakuto R would have carried several payloads to the lunar surface, including the United Arab Emirates' Rashid rover, which was outfitted with scientific instruments, as well as Japan's SORA Q, a baseball-shape rover equipped with a camera. iSpace plans to send a second lander to the Moon as early as 2024. In the meantime, just before its attempted landing, Hakuto R sent back a consolation prize: an image of Earth rising over the lunar limb, taken on April 20th during last week's rare hybrid annular-total eclipse. The image shows the tiny black dot of the Moon's shadow crossing near Australia.

■ DAVID DICKINSON

SHAKE, RATTLE, a

Conquered by dust, the Insight lander has ended its mission after giving us an unprecedented look at seismic activity on the Red Planet.

"My power's really low, so this may be the last image I can send. Don't worry about me though: my time here has been both productive and serene. If I can keep talking to my mission team, I will — but I'll be signing off here soon. Thanks for staying with me."

This was the farewell message from @NASAInSight, the official Twitter account of NASA's Insight lander. For four years, the spacecraft had studied the interior of Mars in an unprecedented way. But dust accumulating on the lander's solar panels had been steadily reducing their power output, to the point that the craft was no longer able to charge its batteries. The image posted with the tweet looked like a car-crash scene from *Mad Max*, a fish-eye view of dust-covered gadgets strewn over an arid landscape.

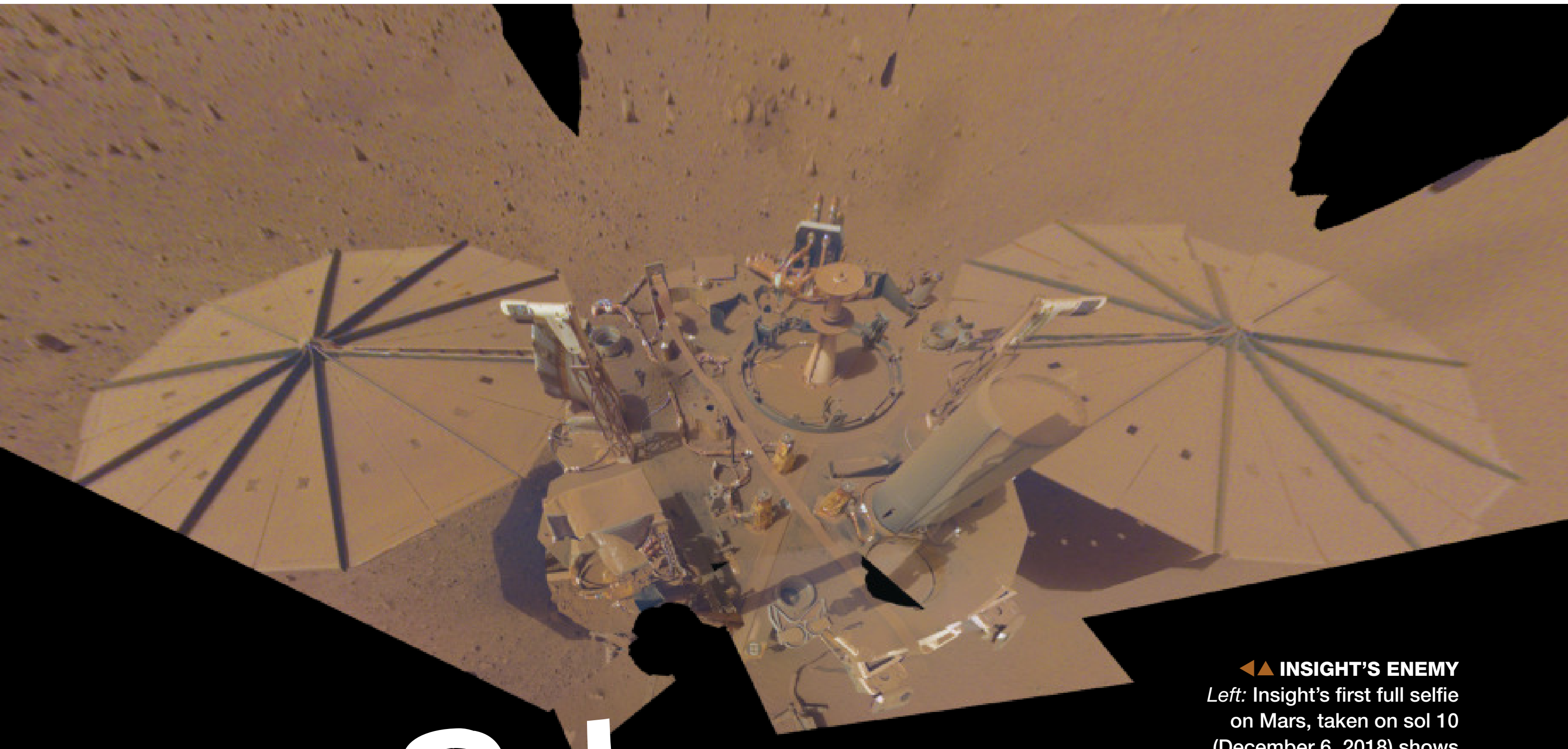
Just two days later, on December 21, 2022, NASA announced that the spacecraft had failed to communicate with mission controllers at the Jet Propulsion Laboratory (JPL) in California. The agency declared the mission over.

"We've thought of Insight as our friend and colleague on Mars for the past four years, so it's hard to say goodbye," said the mission's principal investigator, Bruce Banerdt (JPL), in a press release.

Although Insight doubled its initial life expectancy of two years, Banerdt and the mission team had hoped it would live far longer. But the solar panels' output had started declining almost immediately after landing. Other solar-powered missions have fortuitously had their panels cleared by occasional wind gusts, but the breezes in Insight's location, while strong, didn't remove enough dust. The grime kept building up, until it completely blocked the sunlight.

Nevertheless, Insight was largely a success. It was the first spacecraft to use a seismometer on the Martian

FIRST AND LAST SHOTS OF LANDER: NASA / JPL-CALTECH (2)



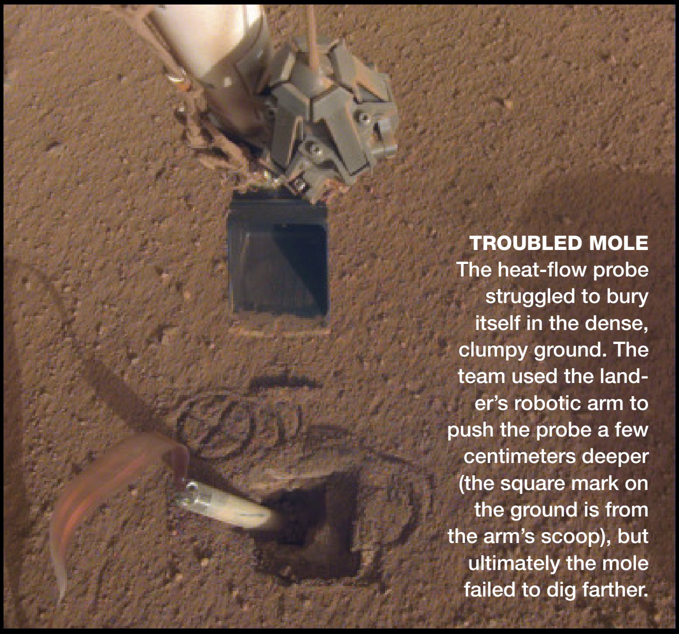
nd ROLL

◀▲ INSIGHT'S ENEMY *Left:* Insight's first full selfie on Mars, taken on sol 10 (December 6, 2018) shows its clean solar panels and deck, with its science instruments still on top. *Right:* The lander's final selfie, from sol 1211 (April 24, 2022), shows it so covered in dust that it's hard to see it against the landscape.

surface to detect the equivalent of an earthquake — a *marsquake* — and opened an entirely new window into the planet's interior. In only a few years, Insight revealed the size of Mars's crust, mantle, and core — something that took 30 years for terrestrial seismology. But it has also left scientists with new puzzles about how Mars formed and how its atmosphere works today.

Off to a Bumpy Start

Insight (Interior Exploration Using Seismic Investigations, Geodesy and Heat Transport) landed on Mars on November 26, 2018, on the relatively flat lowlands of western Elysium Planitia. Its mission was to study the deep interior of Mars. Mars is arguably the most studied planet in the solar system, but previous observations have been of the surface, or what lies above or just beneath. Scientists know little about the planet's inner structure. Yet, this interior holds the answers to how the planet formed and evolved over the last 4½ billion years and, by extension, could tell us many things about the formation of the solar system as a whole.



TROUBLED MOLE The heat-flow probe struggled to bury itself in the dense, clumpy ground. The team used the lander's robotic arm to push the probe a few centimeters deeper (the square mark on the ground is from the arm's scoop), but ultimately the mole failed to dig farther.

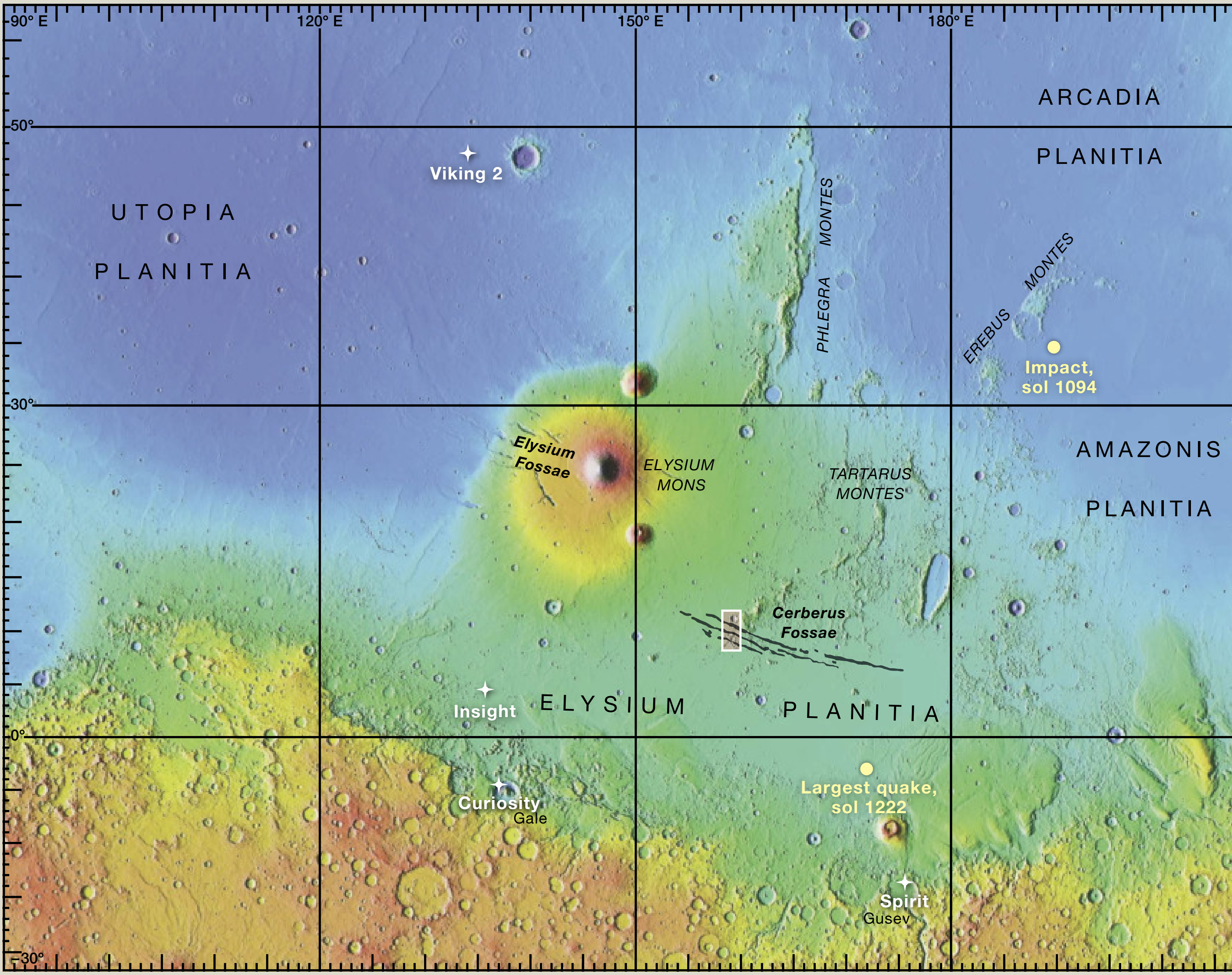
NASA / JPL-CALTECH

Insight carried three main scientific instruments: A seismometer to record marsquakes, a thermal probe to measure the heat escaping from the planet, and a tracking device to study the orbit of Mars with exquisite precision. It also had a robotic arm to put the instruments on the ground, two cameras, and a wide array of sensors to measure wind speed, atmospheric pressure, local magnetism, and other environmental parameters.

The Heat Flow and Physical Properties Package (HP^3) relied on a self-burying device, nicknamed "the mole," to drag a ribbon-like cable studded with temperature sensors to a depth of 5 meters. Its goal was to measure the heat flow from the planet's interior and the thermal properties of the ground. The mole, a pointy metallic cylinder 2.7 centimeters (about an inch) wide and 40 centimeters (16 inches) long, housed a spring-loaded weight that would wind up and hammer the mole downwards with each impact.

The ground beneath Insight wasn't mole-friendly, though. The device had been designed for sandy terrains like those encountered by previous surface missions: It needed friction

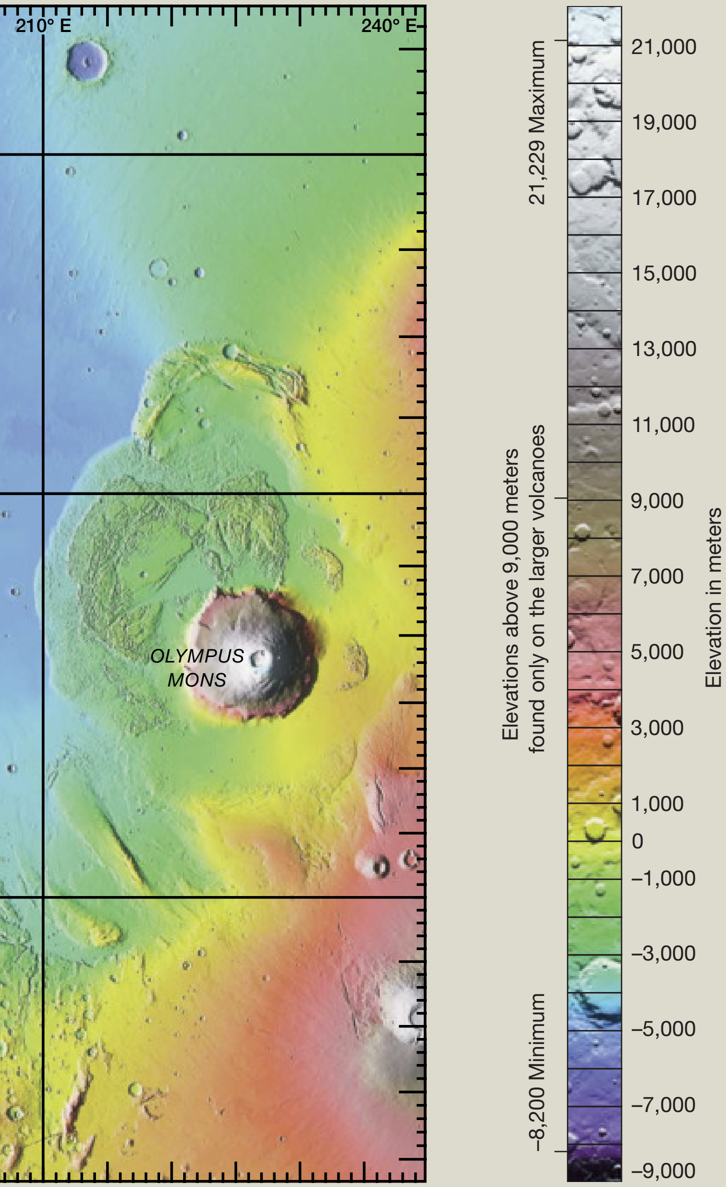
CERBERUS FOSSAE *Below:* Insight landed in Elysium Planitia, north of the Curiosity rover. Most of the marsquakes it detected originated around an extensive fault system called Cerberus Fossae (black lines, box shows close-up section), which is as long as California's San Andreas fault zone. But some of the largest seismic events came from farther away, including the Christmas Eve impact (sol 1094) and a 4.7-magnitude shaker on sol 1222. *Opposite:* Made with data from the Mars Express orbiter, this close-up shows the boxed part of the trench system.

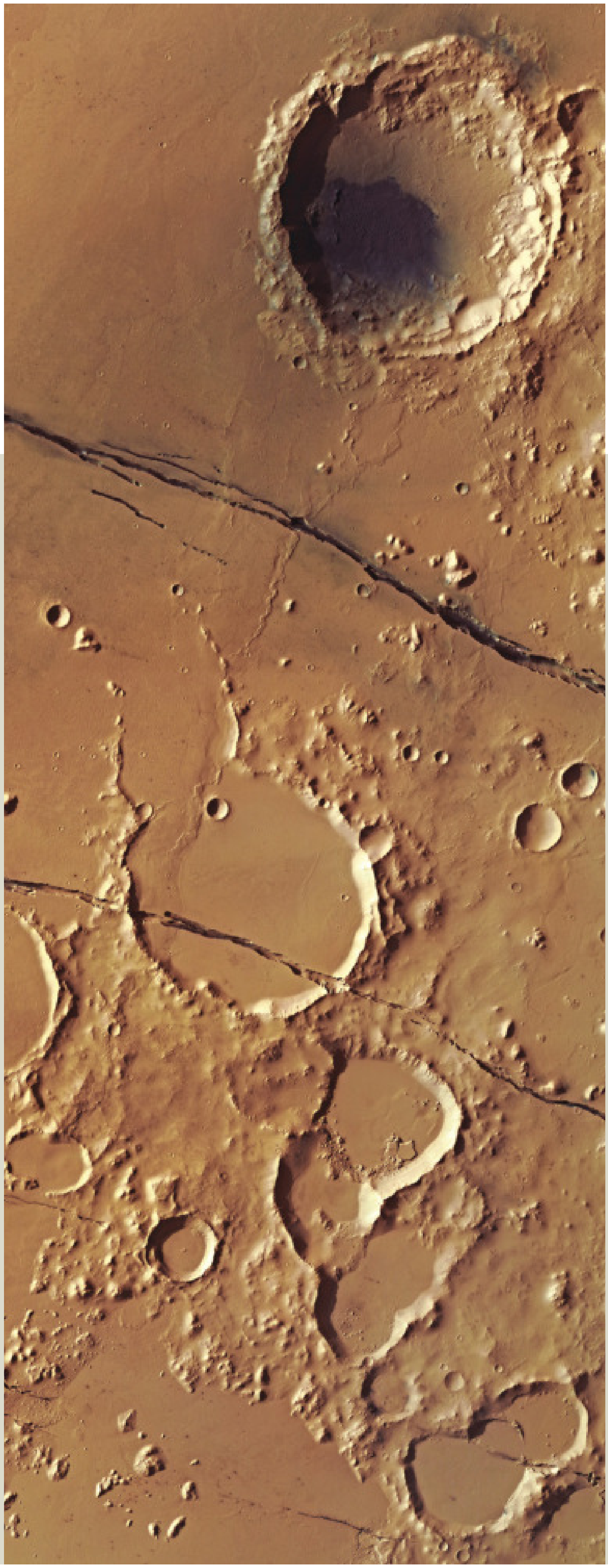


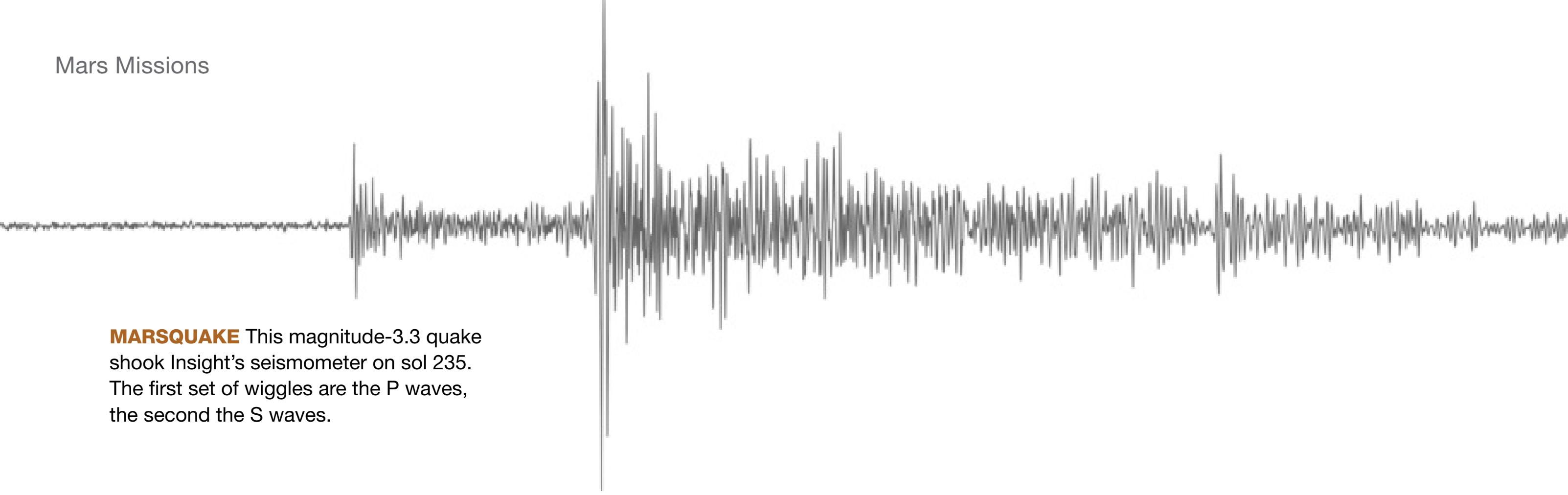
with loose particles to absorb the recoil from the hammering in order to drill. Instead, the landing site was a hard, clumpy terrain, and the mole just bounced in place.

The mission team tried using Insight's robotic arm to help the struggling mole bury itself. They pushed it from different angles, scooped dirt on top of it, and even shoved it into the hole and pinned it with the arm's scoop. It failed to pull itself even an inch farther. The Insight team officially gave up on January 9, 2021, after almost two years of frustration.

It wasn't all in vain, though. The mole measured the thermal conductivity of the uppermost layer of soil. Its hammering also provided a seismic source that allowed the seismometer to collect information on the uppermost layer of the ground and to measure the velocity of seismic waves in the Martian regolith.







MARSQUAKE This magnitude-3.3 quake shook Insight's seismometer on sol 235. The first set of wiggles are the P waves, the second the S waves.

NASA / JPL-CALTECH

Ready to Rumble

As the mole struggled, the seismometer — the real bread and butter of the mission — listened to the murmurs from the Martian underground.

Insight's Seismic Experiment for Interior Structure (SEIS) is the all-terrain vehicle of seismometers. "We were able to provide a seismometer as good as the best portable seismometer on Earth, except that it's able to survive the space environment, very cold temperatures, radiation, et cetera," says Philippe Lognonné (Institute of Earth Physics of Paris), SEIS's principal investigator.

SEIS, like other seismometers, uses a system of pendulums to measure movement caused by seismic waves, which occur when something makes the ground vibrate. It's extremely sensitive, able to detect movements smaller than the size of an atom — so sensitive, in fact, that it needed special shielding from ambient noise and temperature changes in order to operate.

SEIS found that, seismically speaking, Mars is very different from Earth. The first thing scientists noticed is that it's very quiet. On Earth, oceans create a constant seismic buzz that masks faint quakes at long distances. But on Mars, the seismometer could pick up quakes 100 times weaker than it would on Earth.

Researchers could not take full advantage of the seismic silence, though. Mars is very windy, and the seismometer — although covered by many isolating layers and a wind dome — was essentially exposed to the elements. As the wind hit the lander, it wiggled and rattled, transmitting vibrations to the ground. Luckily, the wind died out at night almost like clockwork, leaving a window of six to eight quiet hours when most of the quake detections occurred.

The first quake appeared on Sol 128, after two months of nail-biting wait. It was a faint, 2nd-magnitude tremor, which would be undetectable to human beings on Earth. Before the end of the mission, SEIS recorded 1,319 quakes, with magnitudes ranging from 1 to 4.7. Only a handful of them were above magnitude 4, powerful enough to jingle windchimes but probably not to wake you up at night.

The number of quakes is at the lower end of pre-Insight expectations, showing that marsquakes are both less powerful and less frequent than earthquakes. On Earth, moving tectonic plates constantly produce quakes. But Mars has a single plate, a thick crust that has been cooling and contracting for billions of years like a raisin. The built-up tension occasionally breaks the crust and creates *thrust faults*, where one side of the fault jumps on top of the other. This process accounts for one-third of the total seismic energy released on Mars.

Quakes on Mars also last longer than on Earth. While earthquakes last seconds or minutes at most, marsquakes typically last tens of minutes. Moonquakes, detected by seismometers deployed during the Apollo missions, linger for hours after the initial shake. The key difference is the attenuation produced by a warm interior and liquid-filled pore spaces, two factors that hinder seismic waves. Mars occupies a middle ground between Earth and the Moon in this regard.

4.7

Magnitude of largest marsquake Insight observed (on sol 1222, or May 4, 2022)

Like on Earth, quakes generate two types of seismic waves. *Surface waves* travel on the surface and can only reveal details about the crust and upper layers. *Body waves* travel through the interior of the planet and tell us about its deep structure. They come in two flavors: primary or P-waves, which are compressional waves and travel faster, and secondary or S-waves, which oscillate perpendicular to the direction of propagation and are slower. Researchers can use the difference between the speeds and arrival times of P-waves and S-waves to find the source of quakes. The waves also reveal the properties of the rocks they passed through.

Cerberus Fossae

To the scientists' astonishment, Insight's marsquakes had a favorite source: Cerberus Fossae.

Cerberus Fossae is a fault network 1,200 kilometers long, located 1,500 km east of Insight's landing spot. It's one of the youngest features on the Martian surface, thought to have started forming just 10 million years ago. Scientists suspect ongoing volcanism in the area. Satellite images have revealed lava fields and ash deposits, some of them younger than 50,000 years — not even the blink of a geologic eye.

The flanks of Cerberus's faults don't slide laterally past each other, like in California's San Andreas zone, but seem to be pulling away from each other, opening gaps in the ter-

rain. This area was the source for about 90% of all the quakes Insight detected, accounting for half of the total seismic energy released on the planet as a whole. The large number of quakes shows that the faults are still opening today.

"To produce these opening faults you need an active mechanism," says Insight team member Simon Stähler (Swiss Federal Institute of Technology Zurich). "More and more people are becoming convinced that this could be due to an upwelling in the mantle, a so-called plume."

Mantle plumes are powered by heat coming directly from the mantle-core boundary. They are made by hot but solid rock — not magma — that over long periods, maybe hundreds of millions of years, is plastic enough to flow. Once the plume reaches the bottom of the crust, it pushes from below, opening the fractures. Its heat can also melt rock, creating magma pockets that can produce volcanism.

On Earth, mantle plumes are related to volcanism far from plate boundaries, in places such as Hawai'i. Since there's no plate tectonism on Mars, mantle plumes seem like the most plausible driver of volcanism.

Adrien Broquet and Jeffrey Andrews-Hanna (both at University of Arizona) argue that they've found evidence that this is what happens at Cerberus Fossae. They decided to look at the wider picture, puzzled by the intense seismic activity and recent volcanism.

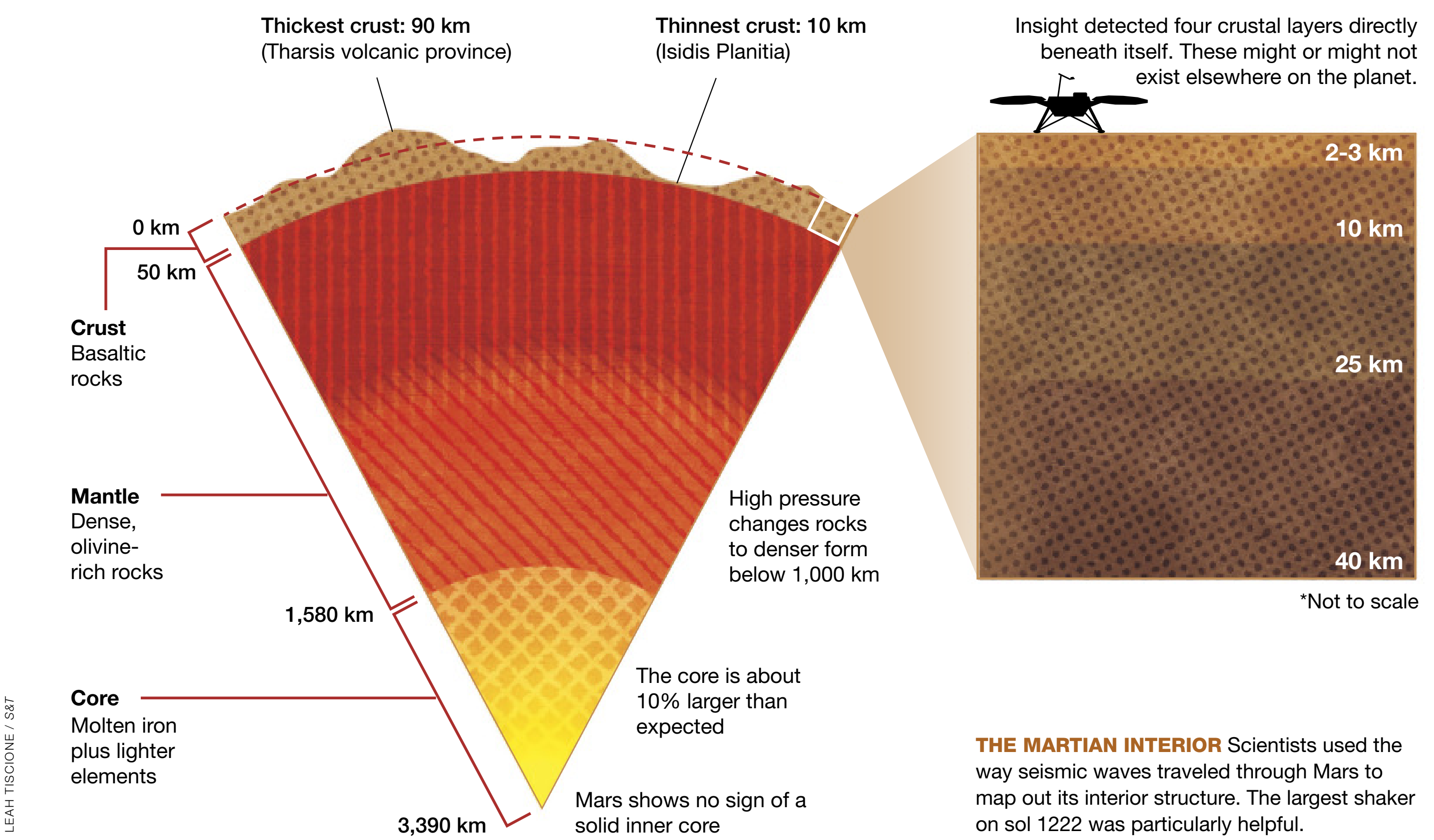
Using satellite observations, they realized that Elysium Planitia, the flat region that includes both Cerberus Fossae and the Insight landing site, rises up to 2 km over the vast northern lowlands, forming a very broad dome. They also spotted subtle gravitational variations, pointing to a build-up of material coming from the deep. More revealing, they saw that the floors of impact craters in the area, instead of being flat, are tilted in the direction of the plume, showing that the ground has moved after the craters formed.

All the evidence points to a mantle plume that is actively uplifting today. It could be as large as 4,000 km wide — roughly the size of the contiguous United States. "That's not something you'd expect from a planet that is cooling," Broquet says.

"It's a bit surprising because it requires quite a bit of activity in the Martian mantle, and for that you need a certain amount of heat," Stähler says. "Since Mars is smaller than Earth, you'd have expected it to cool quicker and generally be much colder in the interior, and that's something people will have to wrap their heads around to explain."

A Multi-layered Planet

Seismic waves are like a flash of light illuminating the planet's interior. As they move through different materials, their speed changes and they are refracted, the same behavior we see with light waves. If the material's properties change abruptly, the waves bounce off and produce echoes, revealing discontinuities that often mark the transitions between the main layers of a planet.



THE MARTIAN INTERIOR Scientists used the way seismic waves traveled through Mars to map out its interior structure. The largest shaker on sol 1222 was particularly helpful.

Insight's measurements confirm that, like Earth, Mars has a crust, mantle, and core. This is unsurprising. But what *is* surprising are some of the details.

The crust is a planet's outermost solid shell. The average crustal thickness on Mars is about 50 km, with a minimum of 10 km in Isidis Planitia and a maximum of 90 km in the Tharsis volcanic province. Earth's crust ranges from 20 km under the oceans to 80 km in its thickest areas.

Insight has detected four distinct layers in the crust directly beneath it. The uppermost layer is only 2 to 3 km deep, and seismic waves travel very slowly through it (at about 1 km/s, or 2,000 mph), revealing that it's very dry, very porous, and likely heavily fractured by meteorite impacts. This layer could be a local feature below Insight's landing site. There are two more discontinuities below, at about 10 and 25 km, but their properties aren't very clear. At 40 km a weaker discontinuity, the *Moho*, marks the end of the crust and the beginning of the mantle.

The *lithosphere* is the upper layer of rigid rock where convection can't happen. It includes the crust and part of the upper mantle. The Martian lithosphere is 500 km thick, twice that beneath Earth's oldest continents. This was expected, since the Martian lithosphere is ancient and has been cooling for a very long time, whereas on Earth plate tectonism continuously recycles this top layer.

The lithosphere acts like a lid that prevents heat loss from a planet's interior. Knowing its thickness, researchers have estimated the planet's heat flow — what HP^3 wanted to measure — to be between 14 to 29 milliwatts per square meter. This is slightly more than expected, but it's still three to five times lower than Earth's.

Deeper down, the mantle looks like a fairly homogeneous layer of silicate rock some 1,500 km thick. On Earth there is a clear distinction between the upper and lower mantle at a depth of 600 km, where the mineral olivine transforms into bridgmanite, a mineral that only forms at very high pressure. The Martian mantle doesn't reach the pressure necessary for this change, although it likely has a weaker discontinuity around 1,000 km, where olivine transforms to wadsleyite. Without the bridgmanite discontinuity, convection in the Martian mantle is largely unhindered, allowing heat from the core to reach the surface more easily.

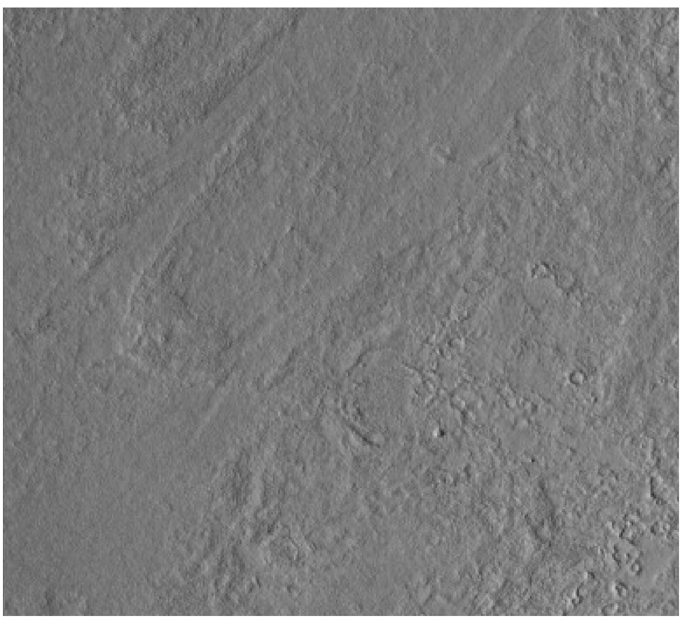
Insight has also confirmed that Mars has a liquid core. S-waves cannot penetrate fluids, so when they reach the core they reflect back to the surface. The Martian core is unexpectedly large, with a radius between 1,780 and 1,810 km. Compared with our planet's interior, Mars's core is proportionally the same size (about half the radius). But Earth has a solid inner core and liquid outer core, and scientists have found no sign of a solid inner core on Mars yet.

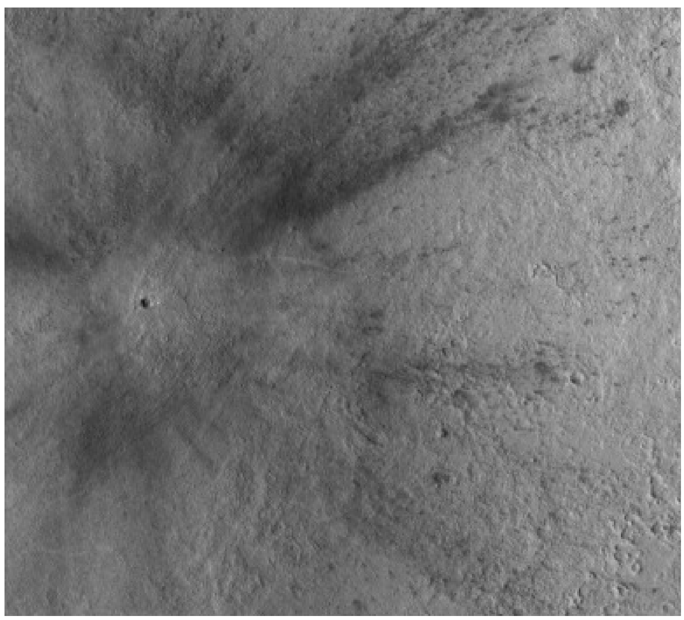
The newfound size means the core is less dense than expected. Mars's core, like Earth's, contains heavy elements such as iron and nickel. But the lower density implies that lighter elements such as sulfur, hydrogen, oxygen, and carbon are a significant part of the core's recipe.

Such a composition, however, does not bode well for planet-formation models. Planetary scientists don't think large quantities of light elements were available for the terrestrial planets as they formed. Plus, to get to the estimated core density of about 6 g/cm^3 would require adding more than 25% sulfur to a pure iron core, which seems unreasonable.

"At the moment geochemists — the people who think [about] how the planets are built — are really unhappy with this result," Stähler says.

One explanation is that Mars might have formed very early in the history of the solar system, at a time when more





NASA / JPL-CALTECH / MSSS (2)

▲ **COSMIC PUNCH** Taken before and after a meteoroid struck, these orbiter images show the impact in Amazonis Planitia on sol 1094 that sent seismic waves traveling through Mars to Insight's seismometer, some 3,500 kilometers away.

light elements were available for planet formation before the solar wind blew them away. Or maybe Mars accreted smaller planetary bodies from the outer solar system, which brought the light elements with them.

A third explanation is the presence of a molten layer of rock at the bottom of the mantle, which would seismically behave like the fluid core, making it look larger than it really is. This idea is still being explored, though.

Hit Me Baby One More Time

On Christmas Eve of 2021, Mars shook more violently than usual. SEIS detected a 4th-magnitude marsquake, among the most powerful recorded. It was the first event to produce surface waves. The epicenter wasn't in Cerberus Fossae, though, but 3,500 km northeast from Insight in Amazonis Planitia, a low, flat plain bordering the vast polar basin.

Two months later, scientists poring over images from the Mars Reconnaissance Orbiter (MRO) spotted a big blotch in this same region. Images revealed a 150-meter-wide crater, surrounded by a large blanket of ejected material that stretched up to 37 km away. Such an impact, scientists estimated, must have been produced by a meteorite 4 m to 12 m in diameter. The crater was 21 m deep and excavated water ice that had lain buried underground, visible as white spots in the satellite image that disappeared over time as the ice sublimated.

Liliya Posiolova (Malin Space Science Systems), the operations lead for MRO, remembered that Insight had reported a large seismic event and realized this impact could be the culprit. Daily weather images taken by another camera on MRO confirmed the date of the impact.

Inspired, Insight researchers looked for similar events in their records, finding that a 4.1-magnitude event that occurred on Sol 1000 (September 18, 2021) was a good candidate. When MRO looked at its epicenter, 7,500 km from Insight, they found a cluster of new craters, the largest 130 m wide.

The surface waves produced by these impacts traveled through the shallower part of the crust to reach Insight. Surprisingly, the waves traveled at roughly the same speed through the northern and southern hemispheres. The topography of the two Martian hemispheres is radically distinct, with a low-lying north that might have hosted oceans and a rugged south made of highlands. On Earth, the oceanic and continental crusts have different densities, something that doesn't seem to be true on Mars.

Weather, Wind, and Dust

As it sat on Elysium Planitia, Insight did more than sense quakes. It also produced an unprecedented set of meteorological records. It measured the atmospheric pressure and wind speed uninterruptedly for over a Martian year, watching conditions change from second to second.

But one thing the lander *didn't* see is dust devils, small dusty tornadoes that are commonplace in other Martian locations. Insight registered thousands of the pressure drops associated with dust devils, but not one was caught on camera — even though vortexes shook the lander and left visible tracks around it.

NASA / JPL-CALTECH

TIME TO SLEEP This image from sol 1436 (December 11, 2022) is one of the last Insight took before it ran out of power. The seismometer's 69-cm-wide protective dome appears at center.

"We have many theories, but we really don't know why we haven't seen a single dust devil," says José Antonio Rodríguez-Manfredi (Center for Astrobiology, INTA-CSIC, Spain), principal investigator for the lander's temperature and wind sensors. Insight has taken daily images of the ground to track how the winds move dust and pebbles over time, and while there's plenty of dust at the landing site, there are still few clues as to why the dust seems reluctant to become airborne in this area. "This is one of the things we don't understand yet."

But there was still enough dust to impact the lander. After four years on Mars, the dust build-up on Insight's solar panels finally blocked more light than the craft needed to recharge its batteries. Ingenious efforts to lower energy consumption and clean the solar panels were eventually not enough, and Insight entered a hibernation state called "dead bus mode," in which everything is disconnected except the circuit that charges the batteries. In the unlikely case that a wind gust clears some of the dust from the solar panels, the spacecraft is ready to resume charging and send a message home: "I'm alive!"

Meanwhile, scientists will keep exploring Insight's data. Currently we are between the second and third generation of Insight results, says Stähler. The first one, he explains, comprised the first observations right after landing, the second included odd or surprising findings, and the third one will consist of new hypotheses to explain all that doesn't add up. "We are entering the third generation of Insight results right now," he says.

JAVIER BARBUZANO is a freelance science journalist who covers astronomy and geoscience.

Williamina Fleming's Deep-Sky Discoveries

From housekeeper to cataloger of myriad stellar spectra, Williamina Fleming continues to inspire.

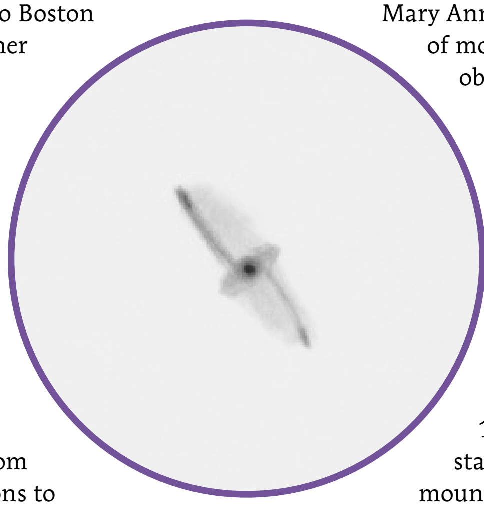
Many articles and books describe the rise to fame of maid-turned-astronomer Williamina "Mina" Paton Fleming (1857–1911) and her contributions to stellar classification. But her deep-sky discoveries may hold a few surprises. In 1879, after emigrating to Boston from Scotland, her husband abandoned her while she was expecting their son. Seeking employment, Fleming found it when Edward Charles Pickering, director of Harvard College Observatory (HCO), hired her as his second housekeeper.

In the late 1870s, Pickering had initiated an ambitious program in stellar *photometry* (precise measurement of stars' brightnesses) at HCO using a visual instrument he devised that he called a *meridian photometer.* During the day, an assistant would transcribe Pickering's observing notes from the night before and then apply corrections to compute stellar magnitudes. Legend has it that the sloppy work of a male assistant upset Pickering so much that he complained that even his Scottish maid could do a better job! Soon afterward, he offered Fleming full-time employment in the lab as a copyist and computing assistant.

The timing corresponded with advances in spectroscopy that shifted the focus of the observatory. In the 1860s, stellar classification relied on time-consuming and exhaustive visual observations made with a spectroscope. Wealthy amateur and pioneering astrophotographer Henry Draper was the first to photograph distinct lines in a stellar spectrum in 1872. By placing a quartz prism in front of the focus of his 28-inch reflector, he captured four hydrogen absorption lines in Vega's spectrum. In the next few years, Henry and his wife, Mary Anna Palmer Draper, recorded the spectra of more than 100 bright stars at his private observatory in New York.

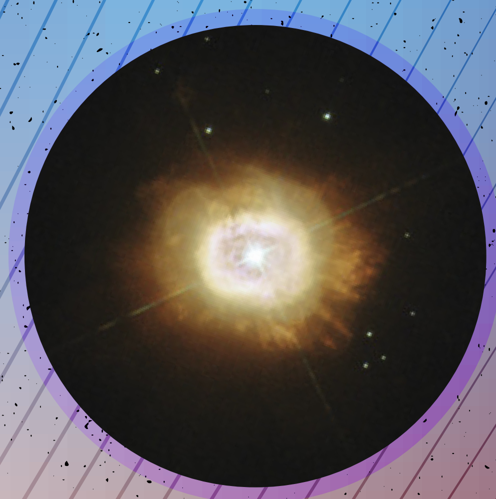
After Henry passed away in 1882, Mary Anna wished to honor and further her husband's spectroscopic research. With encouragement from Pickering, she established the Henry Draper Memorial fund in 1886. Pickering used the endowment to embark on a monumental spectroscopic survey that would last until 1940 and classify 400,000 stars. His key innovation was mounting an objective prism on a short-focus astrograph. This way, instead of recording the spectrum of a single star Pickering captured scores of stellar spectra on each glass plate.

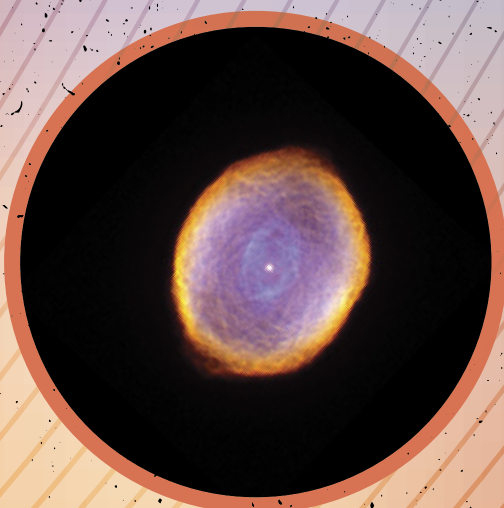
Fleming learned to measure and analyze spectra from Nettie Farrar, one of Pickering's assistants, who was



▲ **SYMBIOTIC BINARY** The relationship between a white dwarf and a red giant, locked in a cosmic dance, gives rise to the complex nature of the clouds of gas surrounding the duo. The red giant itself is variable, which adds to the intrigue of R Aquarii. The drawing was made at the eyepiece of a 27-inch f/4.2 Newtonian at 586×. All sketches have north up.

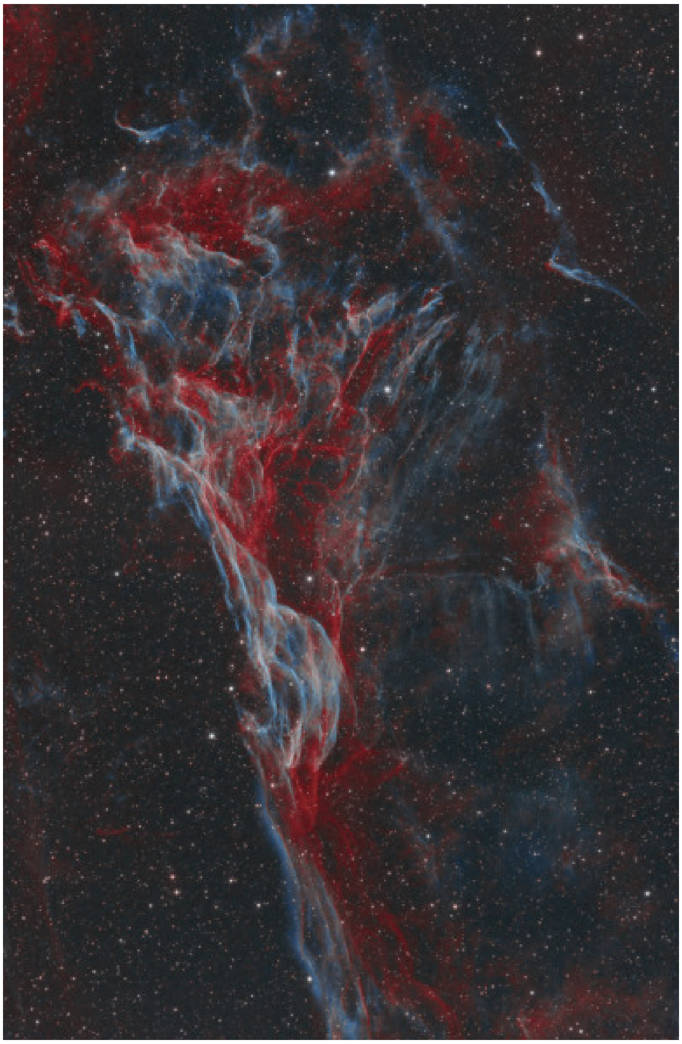
ALL SKETCHES: UWE GLAHN





MINA'S MANY FINDS The photo of Williamina Fleming is from the 1890s — by then, she was already having a significant impact on the astronomical research of the time. Her discoveries include (from lower left to upper right): IC 4634, IC 418, Campbell's Hydrogen Star (imaged by the Hubble Space Telescope), and R Aquarii (captured by the European Southern Observatory's Very Large Telescope).

FLEMING: ART COLLECTION 3 / ALAMY STOCK PHOTO; R AQUARII: ESO; CAMPBELL'S HYDROGEN STAR: ESA / HUBBLE / NASA / JEAN-CHRISTOPHE LAMBRY; IC 418: NASA / ESA / THE HUBBLE HERITAGE TEAM / STSCI / AURA; IC 4634: ESA / HUBBLE / NASA; GRADIENT BACKGROUND: PANIMONI / SHUTTERSTOCK.COM; LINE TEXTURE: A.ARUNO SHUTTERSTOCK.COM; DOT TEXTURE: YURLICK / SHUTTERSTOCK.COM



▲ **LET'S CALL IT BY ITS NAME** Concerted efforts are being made to honor Williamina Fleming as the discoverer of these ethereal wisps in the Veil Nebula in Cygnus, which are still commonly referred to as Pickering's Triangle. Hopefully you'll start to see it more often labeled Fleming's Triangular Wisp.

SARA WAGER

leaving to get married. Fleming also assumed responsibility for examining, classifying, and storing the expanding collection of glass plates. In 1899, Harvard Corporation (one of Harvard University's two governing bodies) appointed her as Curator of Astronomical Photographs, making her the first woman to hold either an observatory or a Harvard University title.

She trained and led a cadre of female "computers," including the remarkable trio of Henrietta Leavitt, Antonia Maury, and Annie Jump Cannon. The work was tedious, and the women were vastly underpaid. But the spectral classification of stars was pivotal in unlocking their chemical composition, physical properties, and evolution.

Fleming's major spectroscopic work appeared in the *Draper Catalogue of Stellar Spectra*, published in 1890 as Volume 27 of the *Harvard Annals*. Using a scheme later dubbed the Pickering-Fleming System, she cataloged the spectra of more than 10,000 stars north of declination –25° and measured their photographic magnitudes. The alphabet soup of spectroscopic types ran from *A* through *N*, based on the strength of the hydrogen absorption lines, called the *Balmer series*. In addition, she assigned the letter *O* to Wolf-Rayet and other emission-line stars, *P* to planetary nebulae, and *Q* to oddballs. Annie Jump Cannon later simplified and refined this system to the familiar *O*, *B*, *A*, *F*, *G*, *K*, and *M* types that we still use today.

Fleming identified 30 planetary nebulae when analyzing the objective-prism plates of the Henry Draper Memorial. She included these in lists of objects with peculiar spectra (variables, carbon stars, Wolf-Rayets, and nebulae) published in Harvard College Observatory *Circulars* and the *Astrophysical Journal*.

While examining a plate taken in 1888 of the Orion Nebula (M42), Fleming discovered the galaxy IC 421 and 10 reflection nebulae. Her analysis also revealed a new emission nebula (IC 434) with a "semicircular indentation 5′ in diameter" — the iconic dark nebula known as the Horsehead Nebula! John Louis Emil Dreyer credited Pickering — as the observatory's director — with discovering these dozen objects in his 1895 edition of the *Index Catalogue* (IC). In 1908, Pickering published a complete table of nebulae found by HCO astronomers between 1848 and 1907, noting who discovered them. He set the record straight on IC 434 but didn't mention Fleming's famous dark indentation.

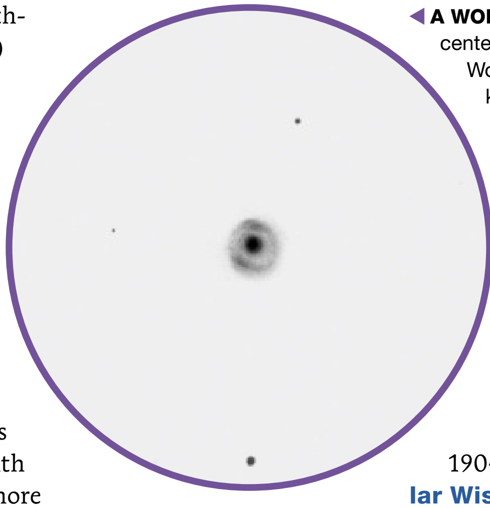
Mina's Marvelous Finds

R Aquarii is a fascinating Mira-type variable (a cool, pulsating supergiant) with a period of 387 days and a visual magnitude ranging from 5.2 to 12.4. German astronomer Karl Ludwig Harding discovered the star's variability in 1811, and, during the century that followed, astronomers considered it a typical long-period variable. Fleming first detected a nebular emission line in 1893. Her log entry from October 17th reads, "faint nebular band 5007, and bright hydrogen lines Hβ [hydrogen-beta] to Hδ [hydrogen-delta] visible, with no trace of the M spectrum."

In 1919, Mount Wilson Observatory astronomer Paul Merrill obtained a spectrum with the 100-inch Hooker telescope and found conspicuous O III emission lines at 5007, 4959, and 4363 angstroms. He noted, "The spectrum may be described as a combination of that of a gaseous nebula with that of a typical star of Class Md [modern classification *M7*e]." In 1922, a third spectrum of the target exhibited bright lines of hydrogen, helium, and iron, indicating a hot companion of class *O* or *B*. Merrill closely monitored remarkable changes in the spectral features from 1928 through 1949.

Lowell Observatory's Carl Lampland photographed the variable in 1921 with the 40-inch reflector and discovered the very peculiar R Aquarii Nebula (also Cederblad 211) associated with the star. Lampland reported, "the most conspicuous detail of this structure is an oval-shaped configuration composed of arcs of well-defined nebular filaments."

R Aquarii lies a bit more than 45′ south-southeast of 4.5-magnitude Omega^2 (ω^2) Aquarii, near the border with Cetus. It's one of the nearest and brightest interacting or *symbiotic* binaries. As the stars orbit each other, the white dwarf siphons off mass from its larger red giant companion. The accreted material piles up and sporadically triggers an explosive outburst. The nebula's expanding shells point to two major ejection events as recently as 640 and 180 years ago. An inner bipolar outflow of gas produces short, curved jets towards the northeast and southwest, with the northeastern component currently more prominent due to a bright clump that first appeared between 1970 and 1977.



◀ **A WOLF-RAYET IN DISGUISE** The object at the center of Campbell's Hydrogen Star is a rare class of Wolf-Rayet star that is much smaller than its better-known, massive counterparts. The stellar winds of HD 184738, the planetary's progenitor, are rich in carbon and oxygen, instead of nitrogen, as in other classes of Wolf-Rayet stars. Compare this drawing, made at the eyepiece of a 16-inch f/4.3 Newtonian at 697×, with the Hubble image presented on page 21.

The feeble glow of these jets is a challenging target, and I barely glimpsed them years ago with a 17.5-inch reflector — though you may fare better when the star is near minimum in early 2024. Recently I took another look through my 24-inch at 375×. Two thin "wings" extend southwest and northeast from the orange-colored star. The brighter northeastern spike has a sharp edge, while the southwestern wing lacks definition.

On a glass plate dated September 2, 1904, Mina discovered **Fleming's Triangular Wisp**, the third most prominent section of the Veil Nebula supernova remnant (see *S&T:* Sept. 2021, p. 28). In 1906 Pickering announced, "Mrs. Fleming found . . . a large triangular wisp of nebulosity extends southward." Many sources still refer to this nebulosity as Pickering's Triangle or Pickering's Triangular Wisp, honoring the observatory's director, but substituting her name reflects the historical record.

SCIENCE SOURCE

▲ **DISCOVERER OF DEEP-SKY OBJECTS** Williamina Fleming, seated at her desk at right in the photo above, not only assisted Edward Charles Pickering in his role as director of Harvard College Observatory, but she also discovered numerous celestial objects in her own right. Her meticulous work analyzing and cataloging stellar spectra created a fundamental platform for future work on stellar classification.

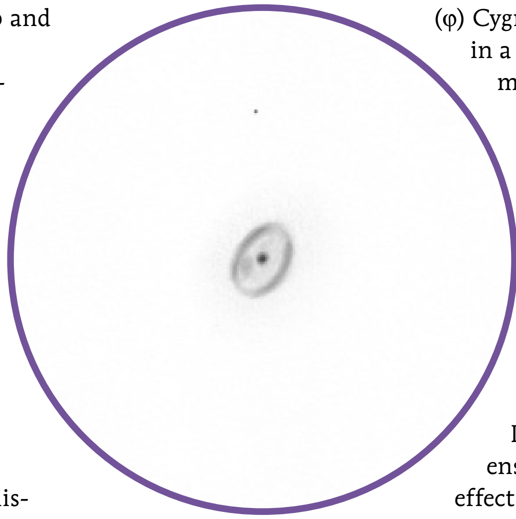
From a dark, transparent site, my filter-equipped 15×50 binoculars show a ghostly, elongated glow to the northeast of NGC 6960, the Veil's bright western branch. Viewed through my 8-inch, Fleming's Triangular Wisp stretches north to south for a length of 45′. At the northern end is a broad bar of mottled nebulosity spreading east to west. Scanning southward, the eastern side of the tapering wedge has a sharply defined, high-contrast edge. The nebulosity constricts further near the southern tip and dissipates into the background sky.

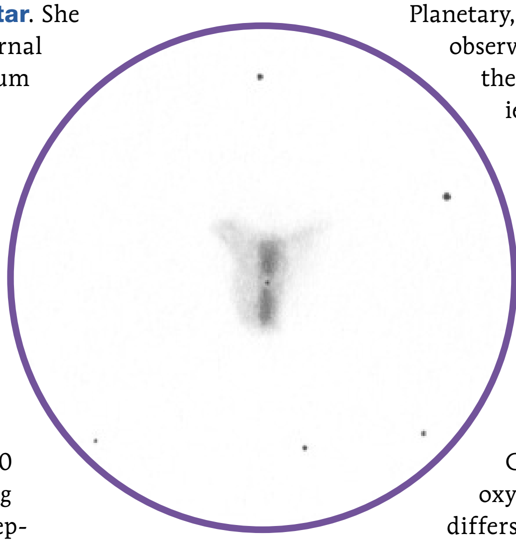
In my 18-inch reflector, the filamentary structure is breathtaking, with several long, thin tendrils scattering in various directions. Some of the curved wisps merge while others crisscross. The southern end shrinks to a width of only 2′, though I can trace it farther as a tenuous, curving thread. The overall length stretches at least 2° across several eyepiece fields.

Rare Red Planetaries

In 1890, Fleming noted the unusual emission lines of **Campbell's Hydrogen Star**. She reported in the German astronomy journal *Astronomische Nachrichten*: "The spectrum of this star differs from that of other bright line spectra of which photographs have been obtained." Either Pickering or an assistant followed up with visual confirmation of the emission lines using the observatory's 15-inch refractor.

Three years later, Lick Observatory astronomer William Wallace Campbell examined the star with a visual spectrograph attached to the 36-inch Clark refractor. He identified 30 bright lines — the most prominent being hydrogen-beta — and concluded its exceptional spectrum resulted from an envelope of incandescent hydrogen. Campbell didn't mention Fleming's earlier report, and astronomers have referred to it by its eponymous nickname since 1920.





▲ **COSMIC SPIROGRAPH** *Top:* The drawing (obtained at the eyepiece of a 20-inch f/4.5 Newtonian at 900×) nicely shows the ring surrounding the central star in IC 418. The Hubble image on page 21 also reveals the delightful whorls and swirls of this graceful planetary, which you'll find in Lepus, the Hare.

▲ **TINY DOT** *Bottom:* IC 5217 is a very small, very compact planetary nebula in Lacerta, the Lizard. Most images reveal a blue hue, which you might even detect with your eye. The sketch featured here instead shows the complex nature of the nebulosity. The drawing was made with a 27-inch f/4.2 Newtonian with magnifications ranging from 837× to 1172×.

Campbell's Hydrogen Star is a very young planetary with an expansion age of 800 years. The low-mass central star displays a spectrum similar to that of a Wolf-Rayet star but with strong carbon emission lines instead of the more abundant nitrogen that their more massive counterparts display (see *S&T:* Aug. 2019, p. 28).

To find Campbell's Hydrogen Star, start at Beta (β) Cygni, or Albireo, and shift 3° northeast to 4.7-magnitude Phi (φ) Cygni. The planetary lies 1° west-northwest in a dense Milky Way field. At low power, it masquerades as an ordinary 10th-magnitude star with two similar stars about 3′ and 7′ northeast. Because of weak O III lines, try confirming it with a hydrogen-beta filter. Campbell's Star is one of the few planetaries that elicits a positive response. When I increase to 300×, my 8-inch resolves a tiny 7″ halo surrounding the star.

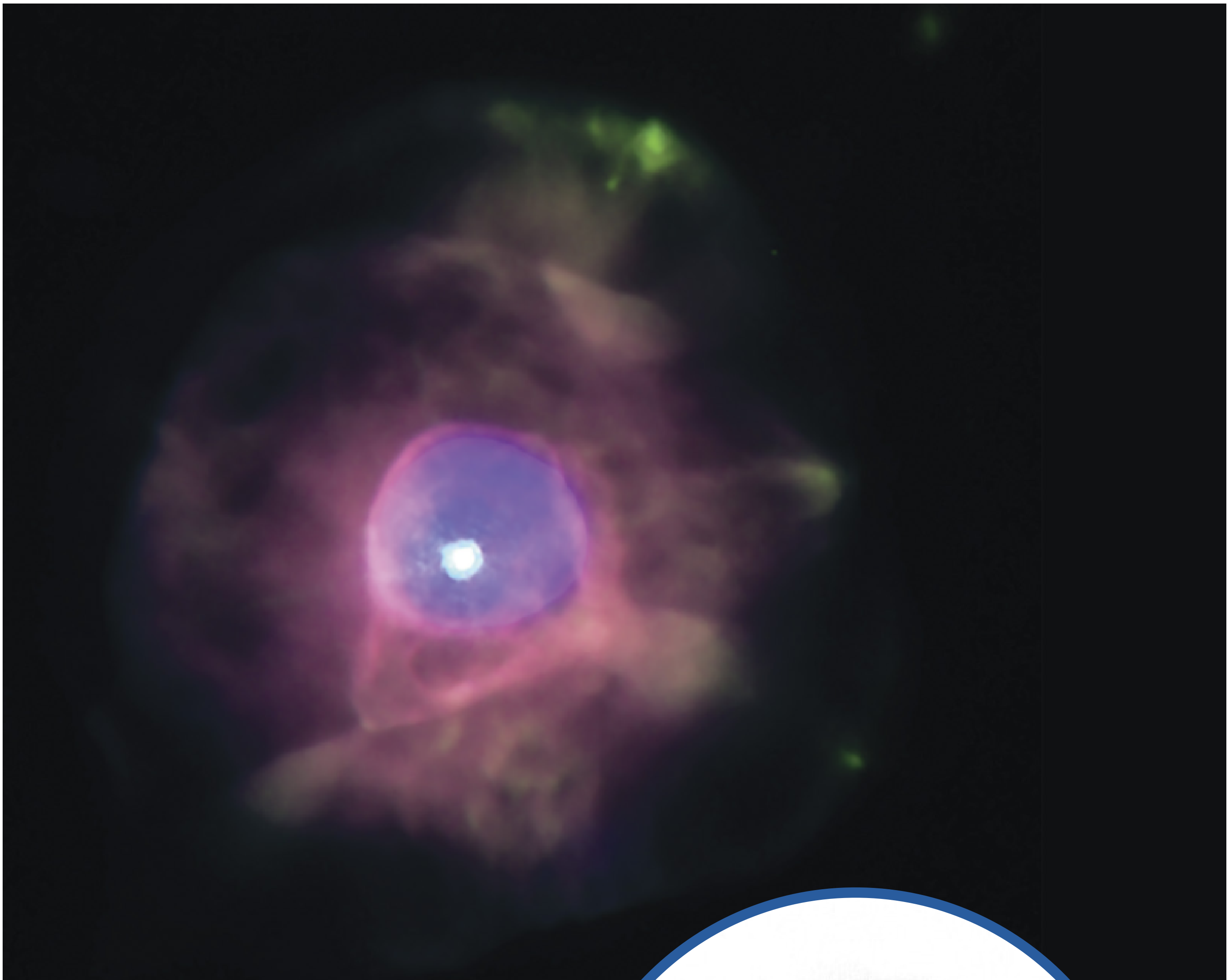
In my 14.5-inch, the mini-aureole nearly vanishes at high power when I stare at the central star, but it brightens up using averted vision. The pulsating effect reminds me of the famous Blinking Planetary, NGC 6826, also in Cygnus. Large-scope observers are in for a special treat. Instead of the blue-green tint found in many planetaries, Campbell's Star sports a red ring.

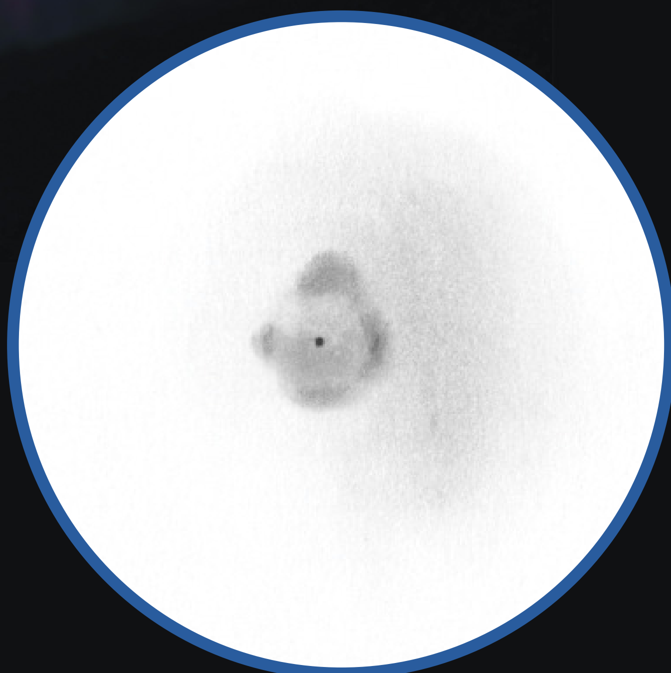
The following year, Fleming identified 9th-magnitude **IC 418** and again noted a peculiar spectrum. (You'll have to wait a few months to catch this one, though, since it lies in the winter constellation Lepus, the Hare.) She found the hydrogen-beta line "unusually strong as compared with the line whose wave-length is 500 [nanometers]," referring to the O III emission line of doubly ionized oxygen. As a result, "the visual spectrum differs strikingly from that of other planetary nebulae."

IC 418, another young planetary, is situated 2° east-northeast of 4.3-magnitude Lambda (λ) Leporis. The Hubble Space Telescope reveals a delicate pattern of interwoven cyclic curves, earning it the moniker Spirograph Nebula. According to a 2017 study published in the *Monthly Notices of the Royal Astronomical Society*, ultraviolet radiation from the central star ionized the nebula only within the past 200 years.

In my 6-inch scope at 100×, a barely discernible fringe encases the prominent 10th-magnitude central star. Through my 8-inch at 229×, a careful look and patience shows the 10″ halo is annular — a perfect miniature ring!

Like Campbell's Star, IC 418 has strong hydrogen-alpha emission that manifests as a red hue in larger apertures. In





HOT HOT GAS Chandra X-ray data of IC 4593, a planetary in Hercules, is in purple in the image above. It reveals the distribution of gas surrounding the dying star that's heated to temperatures of more than a million degrees. The Hubble visible-light image (pink and green) traces the cooler gas composed of nitrogen, oxygen, and hydrogen. The drawing was made at the eyepiece of a 27-inch f/4.2 Newtonian with a magnification of 586×.

NASA / CXC / UNAM / J. TOALÁ / NASA / STSCI

good seeing and transparency, my 18-inch at 150× displays a deep rose or crimson tint along the rim. I find a hydrogen-beta filter smothers the central star, making the nebula easier to distinguish.

Minute Northern Nebulae

In 1904, Fleming discovered **IC 5217**, a very compact planetary in Lacerta. The Reverend Thomas Espin, an accomplished British amateur, made the first visual observations in the fall of 1911 with his 17¼-inch Calver reflector. He estimated its size from 2.5″ to 4″ in diameter and commented it was "apparently elongated N. and S."

IC 5217 is tough to identify in its Milky Way star field, nestled among scores of 12th-magnitude and brighter stars. You'll need to sweep the area 1.2° northwest of 3.8-magnitude Alpha (α) Lacertae. Look for a 7′-long string of 10th- to 12th-magnitude stars, oriented north-northeast to south-southwest. IC 5217 is 7′ to the southeast of the chain and 2′ north of a 10th-magnitude star.

Using my 8-inch, IC 5217 appears light blue and "blinks" strongly at 100× with a narrowband or O III filter. The nearby 10th-magnitude star appeared brighter than IC 5217 unfiltered but fainter in a filtered view. At 175×, I noticed a soft appearance compared to neighboring stars and bumping the power to 400× confirmed a teensy ellipse. Viewed through my 14.5-inch at 660×, IC 5217 spans a scant 6″ by 4″ in a north-south direction.

Fleming picked up **IC 5117**, a petite planetary in Cygnus, in 1905. High-resolution Hubble images show a dense inner disk, 1.7″ by 1.2″, and two tiny pairs of bipolar lobes (hollow shells).

From 4th-magnitude Rho (ρ) Cygni, our 11.5-magnitude target is a short 1° hop to the south-southwest. As IC 5117 forms a double with a 10th-magnitude star just 22″ northeast, it was a snap to identify in my 8-inch. Adding a narrowband filter made IC 5117 noticeably brighter, gaining well over two magnitudes in comparison to the reference stars. It displayed a blue-grey color but was stellar even at 325×.

In my 14.5-inch, IC 5117 is barely nonstellar, with a minuscule disk less than 3″ diameter — and that's using at least 450×. Espin discovered the faint (11th-magnitude) double star Es 1339 just 3′ northeast of the planetary. In the eyepiece, Es 1339 matches IC 5117 and its companion star in separation and position angle!

In 1907, Fleming identified **IC 4593**, often dubbed the White-Eyed Pea. Various studies describe the planetary as a complex system of shells and knots packed in a compact bundle. The inner 10″ disk has a high-density rim. Surrounding the disk is a much fainter shell with collimated outflows to the northwest and southeast, ending in low-excitation knots. The outer halo is 2′ in diameter and contains a curving string of tiny knots towards the southwest.

The Pea is located 3.9° southwest of 4.6-magnitude Omega Herculis and 11′ northwest of STF 2016, a double star with components separated by 7.5″. The 8.5- and 9.6-magnitude pair conveniently point to the planetary.

IC 4593 appears as a 10.3-magnitude bluish star in my 8-inch at low power, though it's slightly soft at magnifications above 100×. A narrowband filter provided a substantial contrast boost, and the planetary outshone a 9.4-magnitude star located 5′ northwest. Viewed through my 14.5-inch scope at 226×, a small high-surface-brightness disk surrounds the bright central star. When I increase to 352×, the halo appears slightly elongated from north to south.

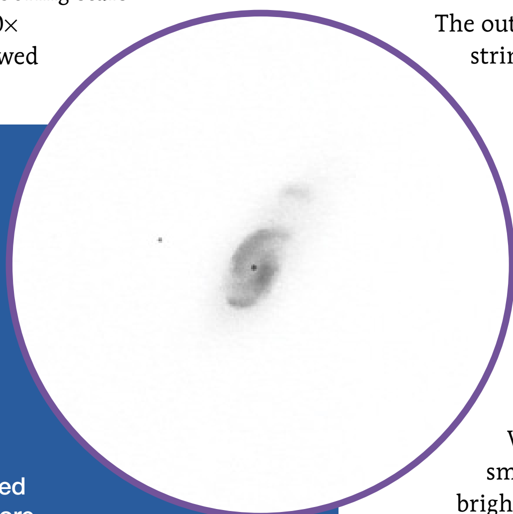
Southern Butterflies

Fleming noted **IC 4634** in 1894 on objective-prism plates taken at Harvard's Arequipa station in Peru. The Hubble image (on page 21) shows a striking feature: two sets of bipolar S-shape wings that imply episodic ejections or jets. The detached outer branches appear shock-excited from an old outflow that plowed into the interstellar medium (called a *bow shock*). The point-symmetry of the jets suggests the central star is part of a binary system. Their interaction causes the energy source to wobble or precess along a rotating axis.

This photogenic planetary is in southern Ophiuchus, 4.6° west-southwest of 4.4-magnitude Xi (ξ) Ophiuchi. There are no bright stars nearby, though several globular clusters are in

Snagging Planetary Nebulae

Most of Fleming's planetaries are small — less than 15″ in diameter — with high surface brightnesses. As a result, you may need to use at least 200× before noticing a fuzzy glow. But how do you identify a stellar planetary at low power? That's easy enough: by "blinking" with an O III or narrowband filter (with a few exceptions). The planetary will appear to light up as the background sky darkens and the filter suppresses the nearby stars.



▲ **LOSING LAYERS** The S-shape outflows from IC 4634 betray several episodic ejection events from when the parent star sloughed off its outer layers. Ultraviolet radiation from the very hot stellar remnant causes the shells of gas to glow. The drawing was made with a 27-inch f/4.2 Newtonian at 837×.

the vicinity, including NGC 6235 some 2° to the west-southwest. In 1982, I logged the color as blue-green, which helped me identify it in my 8-inch Schmidt-Cassegrain. Although it was stellar at 100×, boosting the magnification to 200× revealed a fuzzy glow, and 400× showed a small disk.

In a recent observation with an 8-inch reflector, I noted the planetary as slightly brighter than an 11th-magnitude star 4.6′ south-southeast but fainter than a 10th-magnitude star 1.5′ farther south. A narrowband filter dimmed the stars by two to three magnitudes, allowing IC 4634 to dominate the brighter of the pair. The disk spanned 10″ across at 229×. My 14.5-inch exposed the 14th-magnitude central star using 352×. The high-surface-brightness oval extends 15″ × 10″ and tilts towards the north-northwest.

Mina discovered **Fleming 3** in 1911. This was her final planetary nebula and our most southerly excursion at declination –38.8°. In a Hubble image (at right), Fleming 3 is nearly a dead ringer for Minkowski's Butterfly (M 2-9), with nested hourglass lobes wrapped in a thin sheath (see *S&T:* June 2021, p. 59).

To snag Fg 3, navigate 4° south-southeast of M7, crossing from Scorpius into Corona Australis. From northern California, I tracked it down with my 8-inch as a blue-gray star, less than 1′ northeast of a brighter 10.4-magnitude star. Unfiltered, Fg 3 was dimmer than its companion by at least one magnitude, but the relationship flipped in the filtered view. My 14.5-inch resolves the 14th-magnitude central star at 264× and a high-surface-brightness halo only 5″ across.

Among her stellar accomplishments, Fleming discovered the 7th-magnitude nova IL Normae in October 1893 by its bright hydrogen lines — the first of 10 novae that spectral photography unveiled. In July 1895, she discovered a nova (Z Centauri) near the nucleus of NGC 5253. Astronomers later reclassified it as a Type Ia supernova — one of the earliest extragalactic discoveries. Over her 30-year career, she netted 310 variable stars on Draper Memorial glass plates by their spectral signatures. And in 1910, she made the surprising discovery of the first white dwarf, 40 Eridani B (for the full story, see *S&T:* Dec. 2022, p. 28).

For deep-sky enthusiasts, her tally boasts 59 emission, reflection, and planetary nebulae. Why not visit a few of Mina Fleming's discoveries this month?

▲ **DELICATE LOBES** Fleming 3, in Corona Australis, is a delightful example of a bipolar planetary nebula. Fleming discovered this jewel — the last of her planetary-nebula finds — in 1911.

■ Since completing visual observations of the entire *New General Catalogue* several years back, Contributing Editor **STEVE GOTTLIEB** has been chipping away at the 5,186 entries in the *Index Catalogues*. More than 1,100 of these were discovered at Harvard College Observatory under Pickering's directorship. You can follow his progress at **https:/is.gd/astronomy_mall.**

FINDER IMAGES: Go to **https://is.gd/MinaDiscoveries** for finder charts that will guide your way to the targets discussed here.

Fleming's Discoveries

Object	Alt ID	Discovery Year	Mag(v)	Size	RA	Dec.
R Aquarii	Ced 211	1893	14.5	2′ × 1′	$23^h 43.8^m$	–15° 17′
Fleming's Triangular Wisp	Simeis 3-188	1906	—	45′ × 30′	$20^h 48.5^m$	+31° 32′
Campbell's Hydrogen Star	PK 64+5.1	1890	10.4	13″ × 10″	$19^h 34.7^m$	+30° 31′
IC 418	PK 215–24.1	1891	9.0	14″ × 11″	$05^h 27.5^m$	–12° 42′
IC 5217	PK 100–5.1	1904	11.3	8″ × 6″	$22^h 23.9^m$	+50° 58′
IC 5117	PK 89–5.1	1905	11.5	2.5″	$21^h 32.5^m$	+44° 36′
IC 4593	PK 25+40.1	1907	10.3	13″ × 10″	$16^h 11.7^m$	+12° 04′
IC 4634	PK 0+12.1	1894	10.9	11″ × 9″	$17^h 01.6^m$	–21° 50′
Fleming 3	PK 352–7.1	1911	11.4	2″	$18^h 00.2^m$	–38° 50′

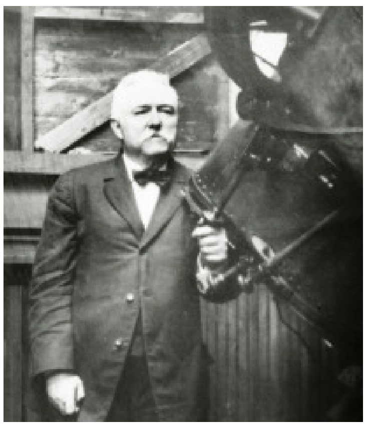
Angular sizes are from recent catalogs. Visually, an object's size is often smaller than the cataloged value and varies according to the aperture and magnification of the viewing instrument. Right ascension and declination are for equinox 2000.0.

E. E. Barnard and his *Milky Way Masterpiece*

One hundred years ago, one of America's most famous and beloved astronomers passed away having written his name across the skies.

On February 6, 1923, American astronomer Edward Emerson Barnard lay dying in the upstairs bedroom of his house on the shore of Lake Geneva, Wisconsin, not far from the two telescopes he loved most — the 10-inch Bruce astrograph he used extensively to photograph the Milky Way and the Yerkes 40-inch refractor, the world's largest instrument of its kind.

Few astronomers have achieved Barnard's distinguished record. His name is forever tied to the eponymous Barnard's Star in Ophiuchus and the nebulous Barnard's Loop in Orion. He's also famously known for his catalog of 369 dark nebulae — some of which are among the most photogenic objects in the night sky. Perhaps Barnard's greatest achievement, however, was his magnificent and monumental photographic tour de force, *A Photographic Atlas of Selected Regions of the Milky Way*.



A Life Under the Stars

Barnard's was a storybook life in which he rose through sheer courage, determination, and genius from a ragged, urchinly existence in Nashville, Tennessee, during the Civil War, to become the virtual custodian of what he called the Milky Way's "glittering star fields." His life was an astronomical odyssey and, in the end, he could say with Odysseus himself, "My fame has gone abroad to the sky's rim."

By 1923, Barnard's health had been poor for years — mainly because of diabetes, which was a death sentence before the availability of insulin. But the astronomer also paid a price for his well-known tendency to overwork. He was an observaholic who refused to let up even on the coldest winter nights and was known to maintain a vigil at the telescope without complaint, even when temperatures dipped to –32°C (–25°F). He would nervously pace the halls at Yerkes waiting for clouds to part to reveal even the smallest scrap of clear sky. When the future Yerkes Observatory director Otto Struve arrived from Russia in 1919, he learned from Barnard "that to accomplish something in observational astronomy we must make use of all clear sky: there is not enough of it to waste by starting late or by being too choosy about the conditions."

Struve recalled that even in failing health, "Barnard was always on duty and no sooner would the sky clear up after a snowstorm than we would hear him opening the dome. It was a familiar sight for us when Mr. Barnard would walk up in the afternoon to the barograph in the library and would sigh deeply and disconsolately if the pressure was going down," foretelling the imminent clouding up of the sky.

On January 13th, 1923 — just weeks before his death — Barnard made his final astronomical observation: an occultation of Venus by the Moon, viewed through his bedroom window. Then, on February 5th, he uttered his last words, which according to his niece and assistant Mary R. Calvert, were: "I don't mind dying, but I am sorry not to finish my work."

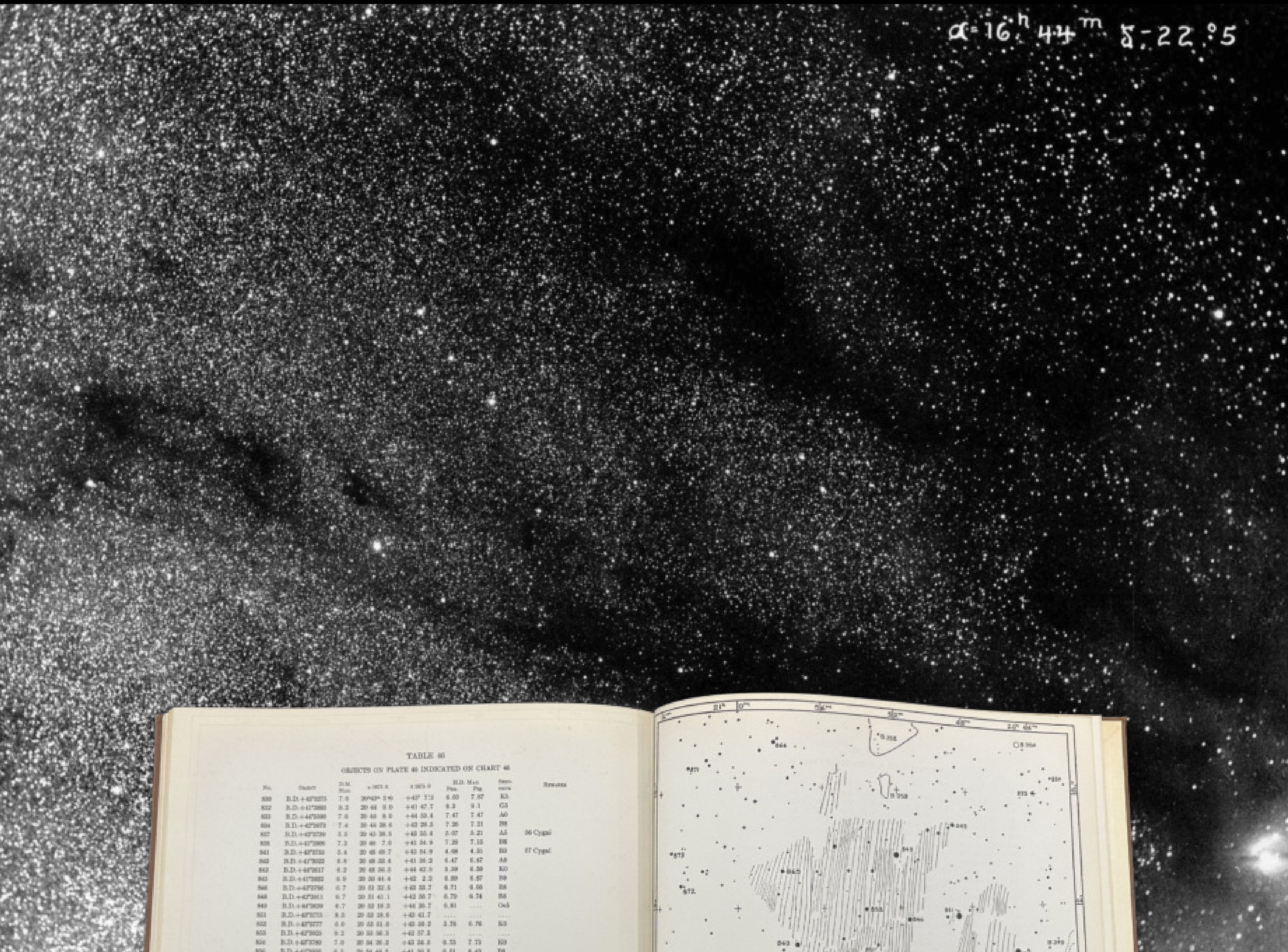
The work he had in mind was doubtless his incomplete *A Photographic Atlas of Selected Regions of the Milky Way*.

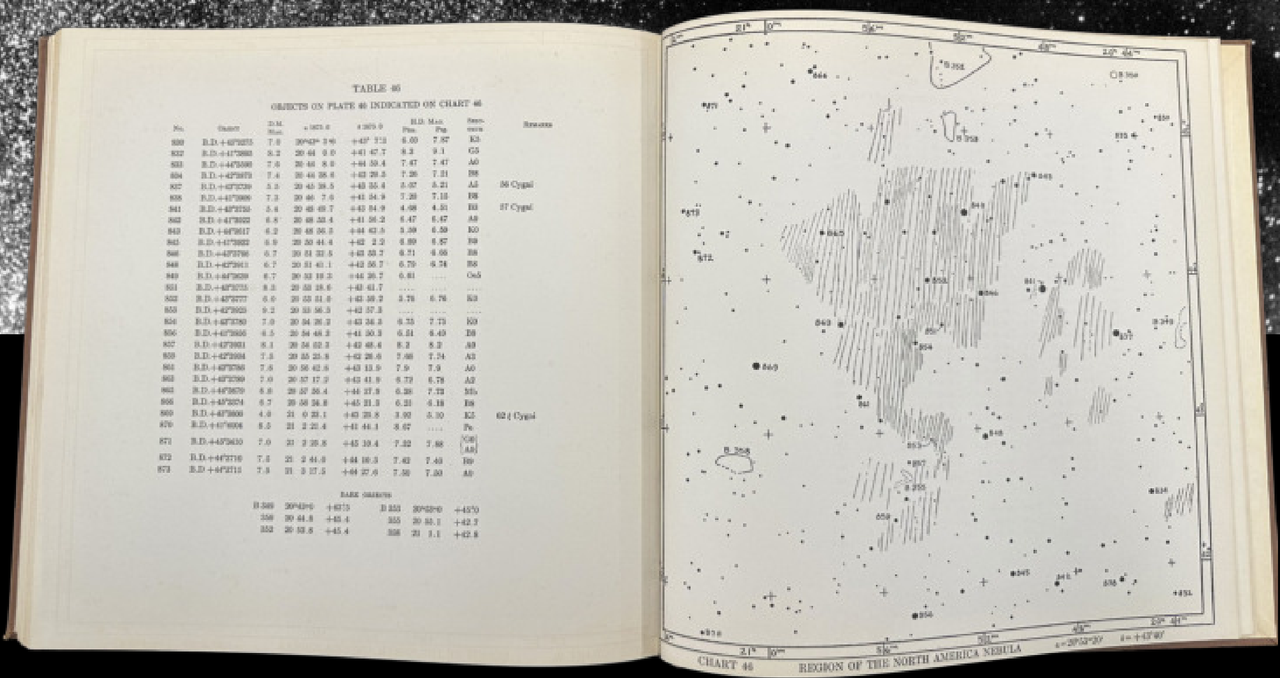
Capturing the Skies

If it's true that one's life flashes before one's eyes just before the end, then what a remarkable series of images Barnard would have been presented with. Perhaps he would have recalled the hardships of his life in Nashville when as a small

▲ **PRODUCTIVE PAIR** Barnard, probably at age 60, stands beside his beloved Bruce telescope. After the 1905 expedition to Mount Wilson, the instrument was returned to Yerkes Observatory, where Barnard continued to use it productively, though the skies at Williams Bay, Wisconsin, were far inferior to those he had enjoyed in California.

BARNARD: UNIVERSITY OF CHICAGO PHOTOGRAPHIC ARCHIVE; PLATE 14: DENNIS DI CICCO; ATLAS PAGES: GEORGIA INSTITUTE OF TECHNOLOGY ARCHIVES AND SPECIAL COLLECTIONS





ATLAS ACHIEVEMENT This magnificent plate, showing mysterious dark lanes extending from the extraordinary region of Rho Ophiuchi, is one of the many stunning wide-angle photographs included in Edward Emerson Barnard's *A Photographic Atlas of Selected Regions of the Milky Way.* The two-page spread shown directly above covers the region of the North America Nebula in Cygnus. Although it mostly collated images captured from Mount Wilson in 1905, the *Photographic Atlas* distilled a lifetime of work. Because of Barnard's impossibly high standards, it was still unfinished at the time of his death in 1923. The *Photographic Atlas* appeared posthumously in 1927, and only then thanks to the efforts of his niece Mary Calvert and Yerkes director Edwin Brant Frost. (The title was suggested by Frost, not Barnard.)

child he lay flat on his back on an old wagon bed studying the stars, whose names he did not yet know. Or the unusual series of bright comets that graced the skies as the Civil War began to rage. Or his humble beginnings as a human clock drive, cranking a set of wheels to keep a giant, rooftop lens aimed sunward to gather light to illuminate portrait sitters in the studio below, where he worked. Or his later career as an amateur discoverer of comets, which led to his becoming a world-famous astronomer and one of the original staff members at Lick Observatory on the summit of Mount Hamilton, California, where he pioneered wide-angle photography of the Milky Way and discovered the fifth satellite of Jupiter.

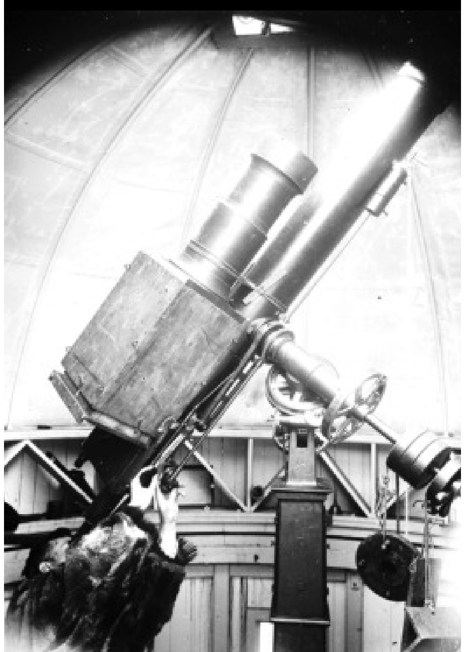
Perhaps, however, he would remember most fondly the time he spent nine months on Mount Wilson in California with the 10-inch Bruce photographic telescope. There, he exposed photographic plates to the glorious, soft light of the Milky Way. Those plates recorded many strange and beautiful wonders, including dark nebulae never before seen by the human eye.

A Solitary Observer

When Barnard came to Mount Wilson in January 1905, the observatory was in a rather rudimentary stage of development. Astronomers had maintained more than a fleeting presence there only since 1903, when Yerkes's brilliant director George Ellery Hale had selected it — with funding from steel tycoon and philanthropist Andrew Carnegie — as the location for a new solar telescope. The site Barnard chose for the Bruce astrograph was a lonely one, between the astronomers' residence (the so-called Monastery) and the observatory workshop. Occasionally, his was the only human presence at the site. He later wrote,

> *I must confess that at times, especially in the winter months, the loneliness of the night became oppressive, and the dead silence, broken only by the ghastly cry of some stray owl winging its way over the canyon, produced an uncanny terror in me, and I could not avoid the dread feeling that I might be prey any moment to a roving mountain lion . . . . So lonely was I at first that when I entered the Bruce house and shoved the roof back I locked the door and did not open it again until I was forced to go out.*

▲ **CAPTIVATING VISITOR** Barnard eagerly photographed Comet Swift (C/1892 E1), whose tail exhibited extraordinary changes. On one occasion he took a stagecoach all the way from San Jose (where he had lectured in the evening) to Mount Hamilton so he wouldn't miss a single observation.



▲ **JUNIOR STAFF ASTRONOMER** Barnard is photographed here wearing his reindeer-skin parka and working with the Lick Observatory's Crocker telescope (fashioned around the 6-inch Willard portrait lens), which he used to photograph comets and the Milky Way.

UNIVERSITY OF CHICAGO PHOTOGRAPHIC ARCHIVE (2)

But when spring arrived on the mountain his mood improved. He was cheered by the insect life that emerged from hibernation and began stirring in the chaparral.

> *The dread of the night soon passed away and the door was left open and it became a pleasure to sit and listen to the songs of nature while guiding the telescopes in long exposures, heedless of all beasts of prey. No one knows what a soothing effect these 'noises of the night' have on one's nerves in a lonely position like that at Mount Wilson.*

After nine months of driving himself incessantly, Barnard's project had gestated, and he reluctantly returned to Yerkes and its dreadful winters, with a treasure-trove of some 500 plates. Of these, the most precious were 154 obtained with the 10-inch Bruce astrograph. Later, in 1907, he received a grant from the Carnegie Institution of Washington, D.C., to publish his Milky Way photographs.

As soon as the grant came through, however, Barnard began dragging his feet. As a result, his *Photographic Atlas* wasn't published until 1927, four years after his death.

The reasons for the delay had a great deal to do with Barnard's rather neurotic personality and perfectionistic nature. In the background lay the bitter history of an almost 20-year struggle to publish his earlier Milky Way and comet photographs taken at Lick Observatory. When Barnard left Mount Hamilton in 1895, his friends and supporters raised a significant amount of money for him to publish his photos. However, progress was hampered by shortcomings in the reproduction methods available

The Strange Odyssey of the Bruce Astrograph

Forty of the 50 plates included in Barnard's monumental *A Photographic Atlas of Selected Regions of the Milky Way* were obtained with the Bruce astrograph at Mount Wilson in 1905. Afterwards, the instrument was returned to Yerkes Observatory and set up in a small dome between the main observatory building and Barnard's house on the shore of Lake Geneva. Although the transparency at Yerkes was generally not as good as at Mount Wilson, Barnard did succeed in obtaining some excellent plates there.

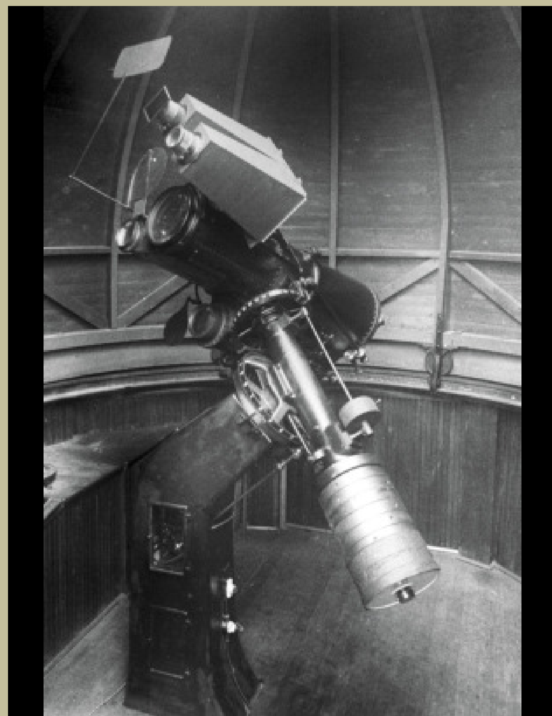
After Barnard's death in 1923, Yerkes director Edwin Brant Frost hired Frank E. Ross, who moved into Barnard's house. Ross was tasked with taking over Barnard's program of Milky Way photography. He realized that by comparing recent plates with Barnard's from 20 years earlier, he could find stars with large proper motions. Ross published his first list of these fast-moving stars in 1925. In addition, he began experimenting with his own wide-angle lens design, which was first employed in a photographically corrected 3-inch f/7 camera. A January 1927 exposure of the Orion Nebula proved to be much better than Barnard's earlier photographs. The Bruce lens was now effectively an antique.

It remained, however, in its picturesque dome on the grounds of Yerkes until around 1960, when it was gifted to the Athens Observatory in Greece. There, it was mounted together with a Fecker 10-inch astrograph and an f/0.8 Rydell Schmidt camera on an equatorial table built by technicians at the Hellenic Navy's shipyards. But it seems to have found little use. Sadly, the instrument battery was demolished years ago, but the historic lenses (originally consigned to garbage bins) were donated to an astronomy facility located on the island of Kefalonia. The optics were never used, and the facility is now abandoned.

For many years I have made strenuous attempts, with the support of the Antique Telescope Society, to repatriate the Bruce lens to Yerkes. There, it could be reunited with the rest of the telescope, which has been stored in the space beneath the floor of the 40-inch Yerkes refractor for many years. Unfortunately, because of obstacles from the local bureaucracy in Kefalonia, the project has languished. I haven't given up, though.

Along with Ithaca, Kefalonia was one of the islands ruled by Odysseus. In the *Odyssey*, the hero returns home after an absence of 20 years. Perhaps, after an absence of 60 years, the Bruce lens may once again return home to Williams Bay.

– DIMITRIS BAROUNIS



▲ **A MOUNT OF MANY INSTRUMENTS** The Bruce photographic telescope's bent pier was Barnard's own idea, and it allowed the telescope to swing freely around in all positions of the instrument. In addition to the 10-inch Bruce astrograph, the mount carries 6¼-inch and 3.4-inch photographic telescopes, a 5-inch visual guide telescope, and two smaller cameras (the twin tapering boxes).

▲ **MIGHTY MACHINE** Barnard is photographed seated at the Bruce 10-inch photographic telescope on Mount Wilson. In addition to the 10-inch Brashear lens, a 6¼-inch Voigtländer lens, a visual guide telescope, and a smaller camera all shared the same mount.

UNIVERSITY OF CHICAGO PHOTOGRAPHIC ARCHIVE (2)

at the time: collotype, photogravure, and halftone. Frustrated by the poor results, Barnard let the matter drop and eventually became eager to wash his hands of the project entirely. In 1907 — while struggling with bronchitis from observing in the cold — he wrote to a former Lick colleague, "Life is short and uncertain, and I can't stand the strain any longer . . . I would rather die than to have a faulty work go out." He even wrote a check to Lick Observatory director William Wallace Campbell for $1,000, taking financial responsibility for the money already spent on prints that he did not regard as good enough.

Campbell, however, was a stubborn man and refused to let Barnard off the hook. Finally, in 1914, with Barnard finally accepting the photogravure process he had previously rejected as (perhaps barely) adequate, his Milky Way and comet photographs appeared as Volume XI of the *Publications of the Lick Observatory*. Only now did he turn his attention to the Mount Wilson plates.

An Atlas Emerges

Yerkes Observatory director Edwin Brant Frost convinced Barnard that photographic prints would most faithfully reproduce the details contained in the original negatives of the Mount Wilson images. Barnard selected 50 of the best and then painstakingly created a second negative of each one to use for making the prints. In this way, details that otherwise would have been lost were preserved, and the contrast in faint regions was increased. A Chicago firm of commercial photographers, Copelin & Son, was hired to make 700 prints from each of the copied negatives. Each print was carefully mounted on muslin, and Barnard traveled to Chicago several times to personally inspect them, one by one. By 1917, all 35,700 prints were completed, but the book was still far from ready.

Not only was Barnard's health beginning to fail, but he proved incapable of taking time off from his astronomical work. Writing reports on

▲ **ABLE ASSISTANT** Barnard's niece, Mary Ross Calvert, was his indispensable personal assistant from 1914 until his death. She remained at Yerkes until her retirement in 1946 and is pictured here viewing through the observatory's 12-inch refractor. Calvert was largely responsible for sorting Barnard's papers and photographs after his death to produce *A Photographic Atlas of Selected Regions of the Milky Way*.

▲ **YERKES GIANTS** Barnard (foreground) and Yerkes director Edwin Brant Frost stand on the walkway of the northwest dome, then housing the 24-inch reflector built by George Willis Ritchey and used for deep-sky photography. This photograph was taken about 1915, when Barnard published a catalogue of the first 182 "B" objects in *The Astrophysical Journal*.

important new observations took precedence over everything else. Indeed, several new publications documented his emerging realization that the dark objects present in his Milky Way photographs weren't simply vacancies and chasms, as believed. Instead, they were obscuring clouds of interstellar matter set against the backdrop of more distant stars. The most important of his reports appeared in *The Astrophysical Journal*: "Dark Regions in the Sky Suggesting an Obscuration of Light" (1913), "A Great Nebulous Region Near Omicron Persei" (1915), "Some of the Dark Markings in the Sky and What They Suggest" (1916), and "On the Dark Markings of the Sky with a Catalogue of 182 Such Objects" (1919).

In 1919, Barnard wrote almost plaintively to Robert S. Woodward, president of the Carnegie Institution, which had provided the grant to publish the *Photographic Atlas*, to explain why it had still not yet been finished:

I have suffered greatly because of my inability to get the volume out. The fault lies entirely with me, but I am blameless so far as any intentional neglect is concerned. For some years I have been badly handicapped with the inability, or very great difficulty, to get anything like this volume finished. It has caused me great sorrow and endless worry.

The prints are all finished and are here at the Yerkes Observatory. . . . The only thing lacking is to complete the descriptive matter. . . . I have endeavored to complete this descriptive part but have each time been disappointed with it, for my brain gets fagged quickly . . .

Among his papers stored in the Special Collections at the University of Chicago are a large number of drafts and discarded papers containing descriptions of the photographs. Many are hardly more than scraps, and their haphazard character suggests a simple case of writer's block in the face of monumental self-demand. Clearly, Barnard knew that the *Photographic Atlas* would be his masterpiece, and he

UNIVERSITY OF CHICAGO PHOTOGRAPHIC ARCHIVE (2)

WRITTEN IN THE SKY This photo (plate 41) from the *Photographic Atlas* shows one of the best known of Barnard's dark nebulae — an object deep-sky enthusiasts informally refer to as Barnard's E. It is located in a dense region of the Aquila Milky Way due west of Gamma (γ) Aquilae and less than 3° northwest of Altair, the bright star at lower left.

DENNIS DI CICCO

was terrified of falling short. In the last several years of his life he had to come to terms with the fact that he wouldn't be able to complete it.

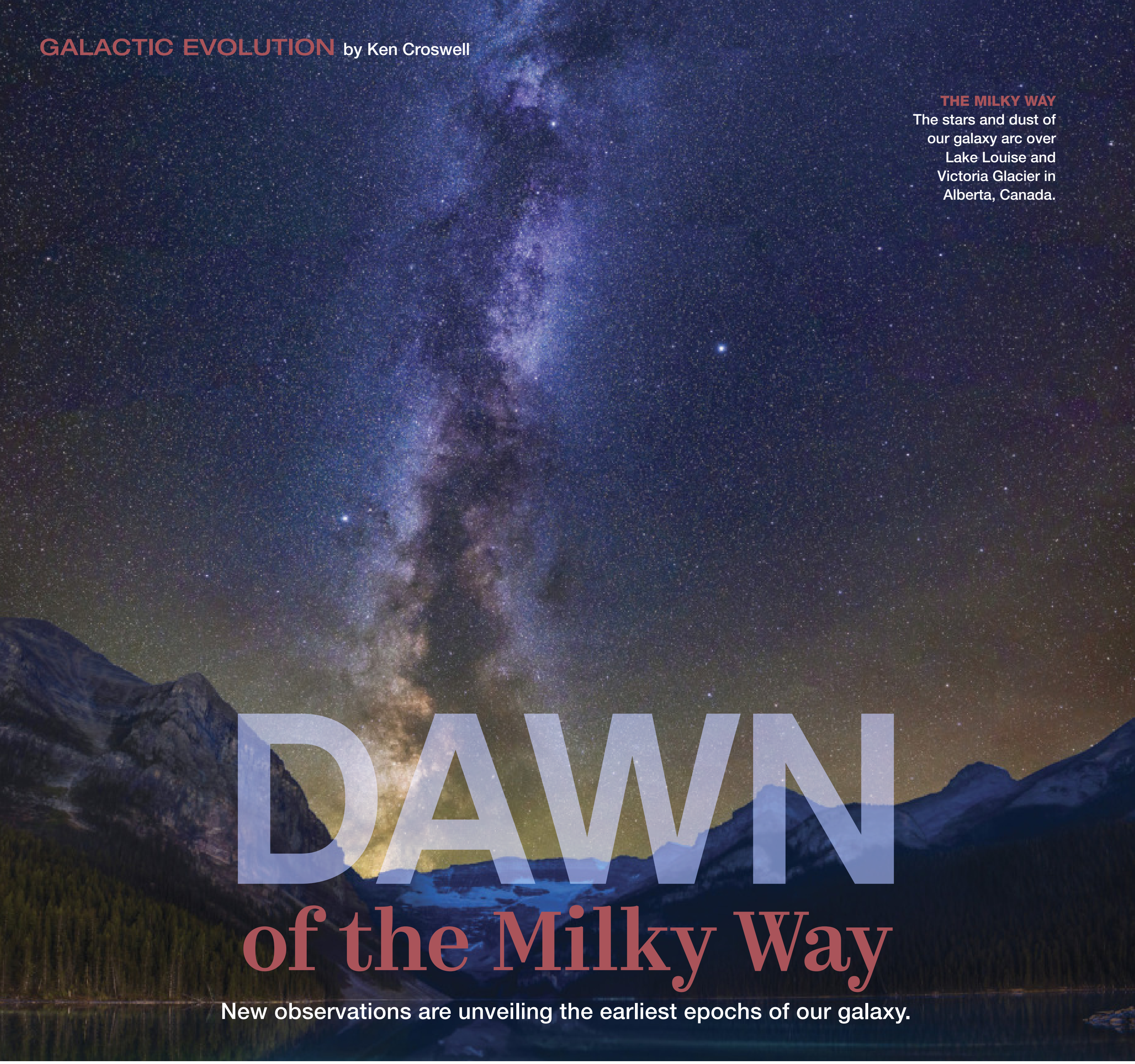
Ultimately, Mary Calvert and Edwin Frost, working from Barnard's papers, brought his opus to conclusion. In 1927 the *Photographic Atlas* was finally published. Working from Barnard's notes, the initial list of 182 "B" objects Barnard had included in his 1919 paper was expanded to 349 by Calvert and Frost. However, Barnard's indications for numbers 175 to 200 had been too vague for the pair to assign object designations. Astronomer Gerald Orin Dobek of Northwestern Michigan College only recently completed that task: He had begun filling in the missing objects right after the republished edition of the *Photographic Atlas* appeared in 2011. Dobek finished his additions in 2022 for inclusion in the forthcoming book *The Barnard Objects: Then and Now* (Springer, 2023), co-authored with Tim Hunter and James McGaha.

Ultimately, it is not the text but the photographs that make *A Photographic Atlas of Selected Regions of the Milky Way* a modern classic. The photographs will never grow old. Indeed, thanks to the efforts of the Georgia Institute of Technology, readers today can peruse a digitized version of the *Photographic Atlas* at **https://is.gd/BarnardAtlas**.

Though new technologies have appeared since the heyday of the silver-halide glass plates Barnard used, his Milky Way images are as complete and perfect as anything human-made can ever be. One of Barnard's acquaintances from his early days in Nashville, Alfred E. Howell, recalled in him "the immortal fire within himself." In the *Photographic Atlas*, the reflected light of that immortal fire shines still.

WILLIAM SHEEHAN became familiar with E. E. Barnard's remarkable career as a preadolescent amateur astronomer, and he later authored the definitive biography, *The Immortal Fire Within: The Life and Work of Edward Emerson Barnard* (Cambridge University Press, 1995).

GALACTIC EVOLUTION by Ken Croswell



THE MILKY WAY The stars and dust of our galaxy arc over Lake Louise and Victoria Glacier in Alberta, Canada.

ALAN DYER

DAWN of the Milky Way

New observations are unveiling the earliest epochs of our galaxy.

We live in a great galaxy, one that's far larger and brighter than most others in the cosmos. Abounding with countless stars and surrounded by dozens of satellite galaxies, the Milky Way is a giant barred spiral with a dark matter halo spanning some 2 million light-years. Our galaxy's disk is spinning so fast that we race along at more than 500,000 miles per hour as the solar system speeds around the galactic center.

But how did this vast entity arise?

Remarkable new discoveries, enabled by the Gaia spacecraft's precise measurements of star positions and velocities, are providing incredible insights into the Milky Way's earliest epochs. These observations reach all the way back to our galaxy's initial chaotic state, when the Milky Way was smaller and just starting to assemble itself. Astronomers are now discovering when the galaxy began to spin, when its disk started to spawn stars, and when its stellar halo formed — all thanks to these new observations of its oldest stars.

Meet the Protogalaxy

Early on, more than 13 billion years ago, our galaxy was hardly the well-ordered system it is today. "It's the time when

the Milky Way was not the Milky Way — it was not a disk galaxy yet," says Vasily Belokurov (University of Cambridge). "It was probably extremely lumpy, extremely incoherent, and kind of amorphous." The early galaxy also only had a fraction of its current mass.

Many of those early Milky Way stars still shine now. As reported in the July 2022 *Monthly Notices of the Royal Astronomical Society*, Belokurov and Andrey Kravtsov (University of Chicago) identified the stars by their chemical compositions. The astronomers knew that the first stars born in the galaxy should have little iron, because the Big Bang that created the universe 13.8 billion years ago made none of the metal; those early stars would have formed from near-pristine gas. Only later did supernova explosions make lots of iron.

But a low iron abundance alone doesn't guarantee that a star is a true native of the ancient Milky Way. Even today, small galaxies have little iron, because they lack the star power to create much of the metal. Some of these little galaxies have crashed into the Milky Way, contributing their own stars. To distinguish iron-poor stars native to the ancient Milky Way from the immigrants, Belokurov and Kravtsov also studied the lightweight metal aluminum.

Rampant star formation produces a lot of aluminum, whereas the iron level rises more slowly. The aluminum-to-iron ratio therefore reveals how fast a galaxy formed its stars, with higher aluminum-to-iron levels indicating quicker starbirth (see "The Aluminum Clock"). Larger galaxies, like the early Milky Way, minted stars at a faster clip than little galaxies, so the astronomers sought iron-poor stars with high aluminum-to-iron levels.

That's how Belokurov and Kravtsov found more than 100 stars born in the proto–Milky Way, a population the researchers dub Aurora. "It's the goddess of the dawn," Belokurov says. "It's the dawn of the formation of our galaxy." These were among the first stars to form inside the Milky Way. They are so old that their iron-to-hydrogen ratios range from just 3% to 5% of the Sun's.

Meanwhile, another research team was uncovering the same pre-disk population and gave it an even more evocative name: the protogalaxy.

"We have found a large set of very metal-poor stars that's tightly confined to the center," says Hans-Walter Rix (Max Planck Institute for Astronomy, Germany), whose team published the discovery in the December 10, 2022, *Astrophysical Journal*. "This is the initial heart or nucleus." The rest of the Milky Way then formed around this kernel.

Finding these stars wasn't easy, because the galactic bulge is crowded with more recent stars. To start, Rix and his colleagues used Gaia data to identify some 2 million red giants located within 30° of the galactic center. To select the oldest stars, the astronomers chose only those with metal abundances between 0.2% and 3% of the Sun's, even more extreme than the ancient Milky Way natives that Belokurov and Kravtsov had found.

By starting with such a large sample, the astronomers located thousands of ancient stars that Rix says represent the very first suns of the Milky Way. Most of these stars lie

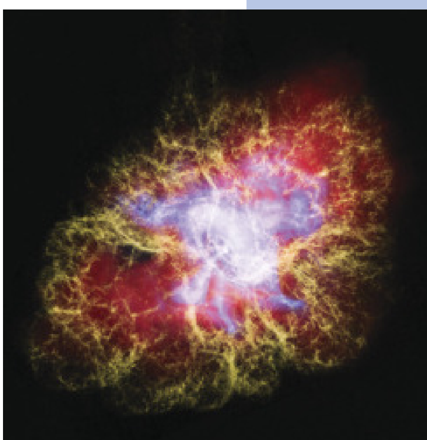
The Aluminum Clock

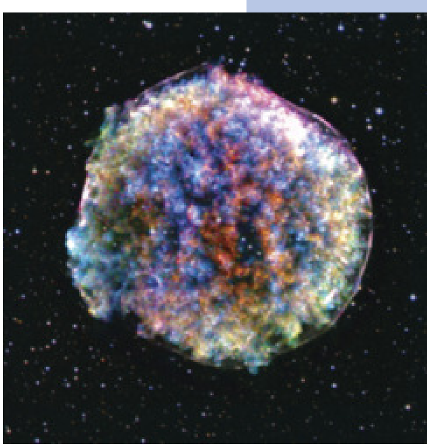
Aluminum can reveal which stars were born in fast-paced galaxies. Such galaxies quickly enrich themselves with carbon, nitrogen, and oxygen as stellar winds and supernova explosions spew these elements into space; newborn stars then inherit the three elements, which catalyze the hydrogen-to-helium fusion reaction via the so-called *CNO cycle*.

The CNO cycle also speeds up the production of aluminum, so the faster carbon, nitrogen, and oxygen emerge from stars, the more aluminum arises too.

The CNO cycle converts some of the carbon and oxygen a star is born with into nitrogen-14. Later in the star's life, two helium-4 nuclei hit some of this nitrogen-14 and create neon-22, a neutron-rich isotope with 10 protons but 12 neutrons. Subsequent nuclear reactions with this neon cause some of those neutrons to end up in aluminum, whose one stable isotope — aluminum-27 — is also neutron-rich, with 13 protons and 14 neutrons.

Thus, as massive stars explode and eject fresh aluminum into space, a big galaxy with a fast-paced lifestyle — like the early Milky Way — builds up its aluminum quickly relative to iron. So stars native to the early Milky Way should have large amounts of aluminum relative to iron.





◀ **REMNANT ELEMENTS** Core-collapse supernova remnants, such as the Crab Nebula *(top)*, contain lots of oxygen and other alpha elements. (X-rays, shown in violet, reveal the spinning neutron star at the remnant's center.) Supernova remnants from exploded white dwarfs, such as Tycho *(bottom)*, possess enormous amounts of iron.

CRAB: NASA / ESA / J. DEPASQUALE (STSCI) / R. HURT (CALTECH / IPAC); TYCHO: X-RAY: NASA / CXC / RIKEN & GSFC / T. SATO ET AL.; VISIBLE LIGHT: DSS

within 9,000 light-years of the galactic center, a third of the Sun's distance. Although the protogalaxy was initially lumpy, today it is round, because the irregularities smoothed out over time. He estimates the protogalaxy has roughly 100 million solar masses of surviving stars.

"We have stars that must have formed very rapidly after the Big Bang, right in front of us," Rix says. "These stars will serve as a very interesting laboratory to understand the synthesis of elements." It's as though some of the Founding Fathers of the United States still lived today, strolling the streets of Philadelphia amid crowds of modern people and ready to answer questions about the finer points of the U.S. Constitution.

And there are plenty of questions to ask. For example, do the stars of the protogalaxy have any gold and platinum? Knowing the answer could pinpoint the cosmic origin of these precious metals: Do they form when massive stars explode, or when neutron stars spiral together? Massive stars explode so soon after birth that if they're the source of gold and platinum, the protogalaxy's stars should have acquired the elements quickly, as exploding stars shed them into star-forming gas. In contrast, it takes a long time for neutron-star binaries to spiral together. If such mergers are the only source of gold and platinum, then the protogalaxy's stars may lack these elements altogether.

Another question: Just how iron-poor are the protogalaxy's most iron-poor stars? "If we can find a true metallicity floor in these stars, I think we have a very interesting handle on what the basic intergalactic-medium metallicity was when these stars formed," Rix says. That metallicity will indicate how much stars enriched the cosmos with metals between the time of the Big Bang and the Milky Way's birth, which in turn will shed light on the intensity of star formation during the universe's first several hundred million years.

The Galaxy Spins Up

Any galaxy that aspires to be a magnificent spiral like ours must spin fast. Rapid rotation whips up the spiral arms that endow these galaxies with their exquisite beauty (*S&T:* Mar. 2023, p. 14). Today the brightest parts of the Milky Way spin quickly, at 240 kilometers per second (540,000 miles per hour).

It didn't used to. The protogalaxy spun little if at all. Rather than revolving around the galaxy's center the way our Sun does, the protogalaxy's stars still dive into and out of it instead.

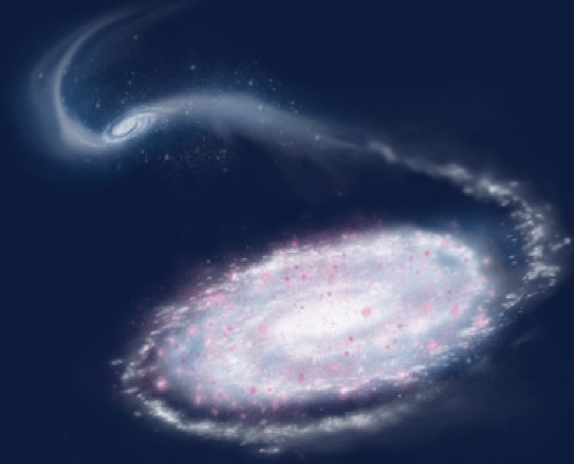
Amazingly, Belokurov and Kravtsov actually see the galaxy's initial spin-up, preserved in the orbits of old native stars that are slightly younger and more iron-rich than the protogalaxy. Over a period of roughly a billion years, as iron levels in these native stars rise from 5% solar to 13% solar, the galaxy spins faster and faster — from 40 km/s at the lower iron level to 140 km/s at the higher. Rix's team also sees the same spin-up.

THE MILKY WAY: A HISTORY This graphic timeline shows the milestones that occurred during the birth and evolution of our galaxy and, ultimately, our solar system.

The Big Bang
13.8 billion years ago

▲ The universe was born in the Big Bang. A flood of light, some dark matter, and a smattering of ordinary matter — mostly hydrogen and helium — emerged.

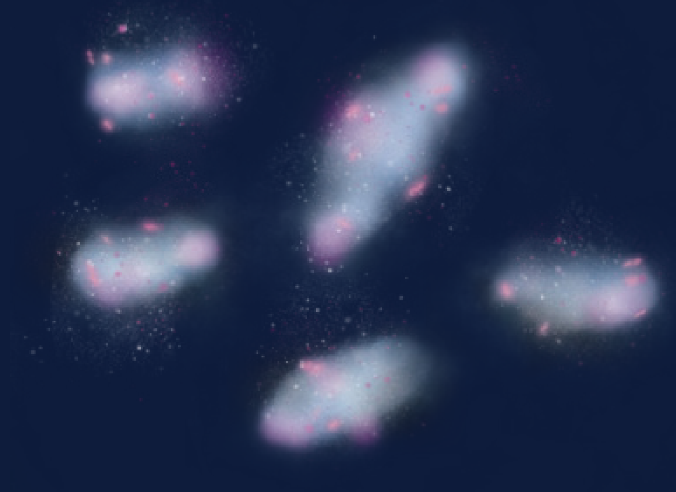
The Stellar Halo Forms
Exact time unknown;
sometime between 11 and 8 billion years ago



▲ Sometime between 11 and 8 billion years ago, another substantial galaxy smashed into the Milky Way. This collision both splattered the intruder's metal-poor stars into the Milky Way's stellar halo and splashed some of the stars from the Milky Way's thick disk into the halo.

The Protogalaxy

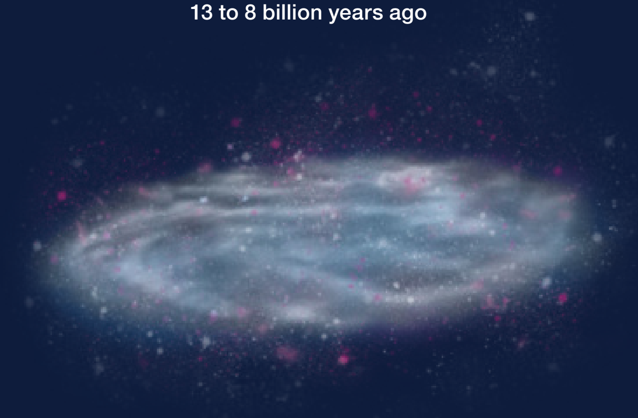
More than 13 billion years ago



▲ The Milky Way began to form more than 13 billion years ago, when several blobs of gas and young stars came together under the force of gravity. Although the most massive stars in these blobs died long ago, millions of other stars in the protogalaxy survive to this day in the Milky Way.

The Thick-Disk Era

13 to 8 billion years ago



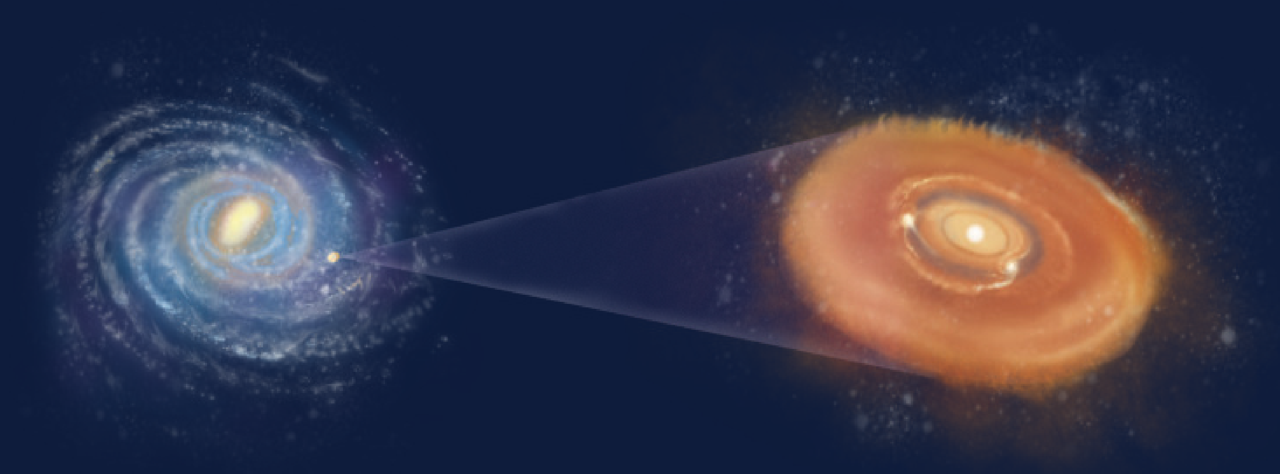
▲ Rapid star formation characterized the era of the thick disk, which created its stars between 13 and 8 billion years ago. As it did so, supernovae raised the iron level. The first thick-disk stars, formed 13 billion years ago, have only one-tenth the solar iron abundance, while the last to form, 8 billion years ago, have three times more iron than the Sun.

The Thin-Disk Era

8 billion years ago to today

Birth of the Sun and Earth

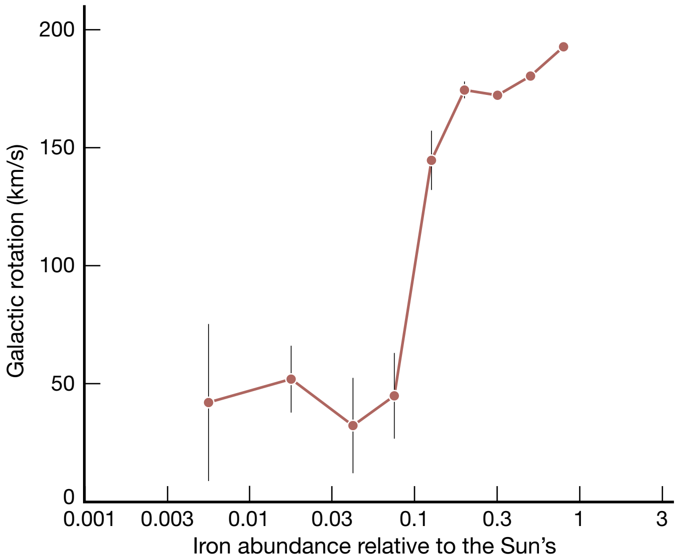
4.6 billion years ago



▲ About 8 billion years ago, after fresh gas fell into the Milky Way, the galaxy started forming stars in a thinner disk that has probably grown in diameter over time. Today the thin disk emits most of the galaxy's light. The Sun and the majority of its neighbors belong to the thin-disk population.

▲ The Sun and the rest of the solar system arose in the thin disk of the Milky Way 4.6 billion years ago. The Sun now lies 27,000 light-years from the galactic center, but it probably formed closer in and has been slowly pushed outward by the galaxy's spiral arms.

BEATRIZ INGLESSIS / S&T



▲ **THE SPIN-UP** As supernova explosions enriched the Milky Way with more and more iron (horizontal axis), the galaxy spun faster and faster, as reflected by how quickly stars revolve around the galactic center (vertical axis). A great leap in galactic rotation occurred when the galaxy attained an iron-to-hydrogen ratio around 1⁄10 of the Sun's.

"This is the Milky Way trying to become a disk galaxy," Belokurov says — like a child learning to walk.

The Birth of the Galaxy's First Disk

The modern Milky Way has two stellar disks that are aligned with and embedded in each other: the *thick disk*, which formed first, and the *thin disk*, which we belong to. In the Sun's vicinity, the thick disk is about three times thicker from top to bottom than the thin disk: 6,000 light-years versus 2,000 light-years. Because we live in the thin disk, most of our neighbors, such as Alpha Centauri, Sirius, and Procyon, are thin-disk stars, but thick-disk stars pass us by, too. A likely example is Barnard's Star, an old red dwarf just 6 light-years from Earth.

But when did the thick disk start to form? Surprisingly soon after the Big Bang, according to work published March 2022 in *Nature* by Maosheng Xiang (now at National Astronomical Observatories of China) and Rix.

Xiang and Rix measured the ages of about 250,000 subgiants, stars that are slowly expanding as they move from the main-sequence phase — when they turn hydrogen into helium at their centers — to the red-giant phase. The temperature and luminosity of a subgiant reveal how old it is, enabling the astronomers to establish a precise timeline for the Milky Way's life story.

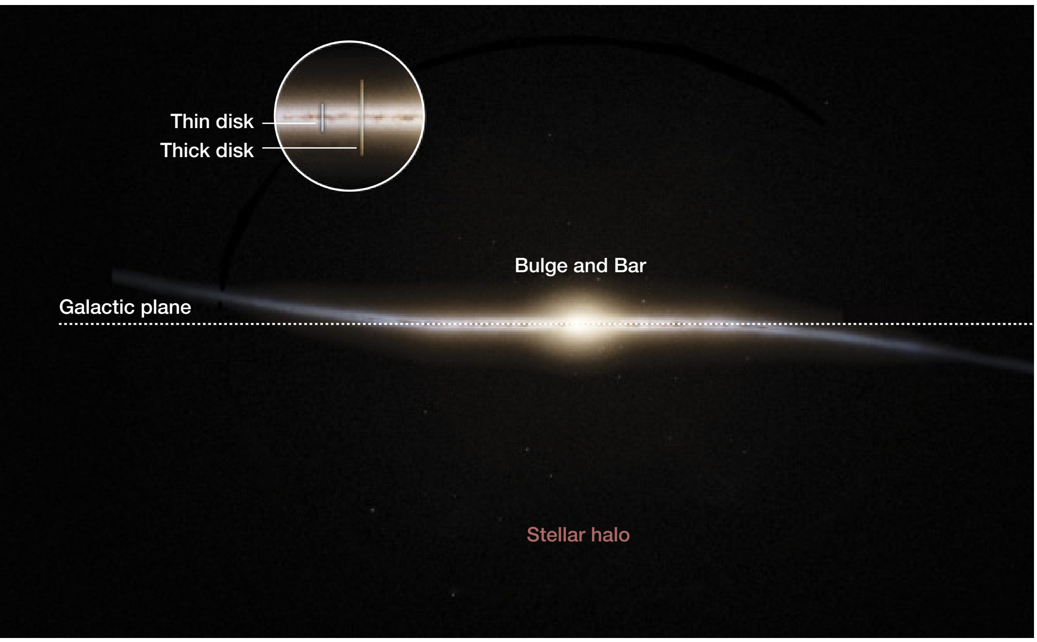
"The thick disk began to form 13 billion years ago," Xiang says. "That means the disk had been there at that time, even earlier than the stellar halo." The thick disk therefore existed a mere 800 million years after the Big Bang.

Furthermore, the measured ages of the subgiants reveal that the thick disk kept forming stars for a long time — up until about 8 billion years ago. During that lengthy period, exploding stars steadily enriched the thick disk with more and more iron. The oldest thick-disk stars, dating back 13 billion years, have iron-to-hydrogen ratios 10% of the Sun's, Xiang and Rix find, while the youngest, born 8 billion years ago, are three times *more* iron-rich than the Sun. The typical thick-disk star is about a third as iron-rich as the Sun.

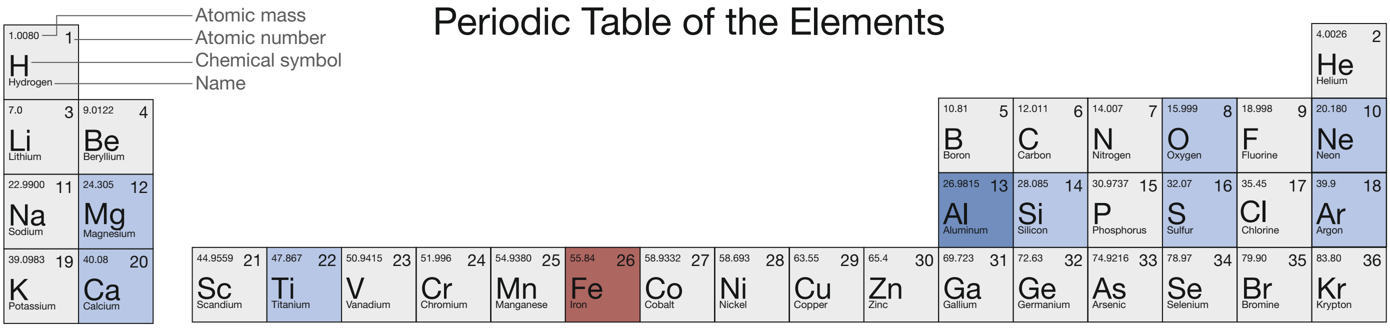
The metallicity of stars in the thick disk corresponds tightly to their age. "That means that the gas in the disk must have been well mixed," Xiang explains. "Otherwise, we would see the inner part have a higher metallicity and the outer part have a lower metallicity."

Meanwhile, another team, led by Charlie Conroy (Center for Astrophysics, Harvard & Smithsonian), has discerned

TWO DISKS Today's Milky Way, shown here in an edge-on artist's illustration, contains two disks: One is thick (about 6,000 light-years tall in the Sun's vicinity) with older stars, the other thin (2,000 light-years near the Sun) with younger stars. A sparse halo of old stars surrounds and penetrates the disk. (Dark matter, not pictured here, populates a far more massive halo that extends about a million light-years from the galactic center.)



GRAPH: LEAH TISCIONE / S&T; SOURCE: C. CONROY ET AL. / ARXIV:2204.02989; THIN VS. THICK DISK: STEFAN PAYNE-WARDENAAR / MPIA



▲ **COSMIC ELEMENTS** Different types of stars made different elements heavier than hydrogen and helium. Almost as soon as the Milky Way was born, short-lived massive stars quickly minted and ejected lots of alpha elements, such as oxygen and magnesium (light blue), plus the non-alpha element aluminum (dark blue). In contrast, exploding white dwarfs, which evolve from longer-lived stars, cast lots of iron (red) into the galaxy.

additional clues, as they posted on the arXiv preprint server in 2022. "The early galaxy underwent a really rapid transition from what we call a simmer to a boil," he says. "At the very early times, the galaxy was very bad at forming stars — it was very inefficient — and then at some moment in time the galaxy transitioned to a period of very efficient star formation."

That transition happened about 13 billion years ago. "I think what we are witnessing is the very emergence of the early galactic disk," Conroy says. During this time, the stars' orbits around the galactic center became more circular. "I would liken this to a phase transition," he adds, like liquid water freezing to ice.

The clue comes from *alpha elements* — elements that, like aluminum, signify rapid star formation when they are abnormally abundant relative to iron. Alpha elements are common in the cosmos, and they all have even atomic numbers: oxygen (atomic number 8), neon (10), magnesium (12), silicon (14), sulfur (16), argon (18), calcium (20), and titanium (22). Astronomers call them alpha elements because the dominant isotopes of all but titanium consist of stuck-together helium-4 nuclei (two protons and two neutrons), which physicists call alpha particles: Oxygen-16 is just four stuck-together helium-4 nuclei; neon-20 is five stuck-together helium-4 nuclei; and so on.

What stuck those helium nuclei together? If you're reading this magazine, you know the answer: stars! In particular, stars born more than eight times as massive as the Sun created most of the oxygen you're breathing, the magnesium in milk and dark chocolate, and the silicon in Silicon Valley.

These massive stars didn't live long. Shortly after birth, most of them exploded, ejecting a torrent of oxygen and other alpha elements into space. Thus, almost as soon as the Milky Way started making stars, it acquired lots of alpha elements.

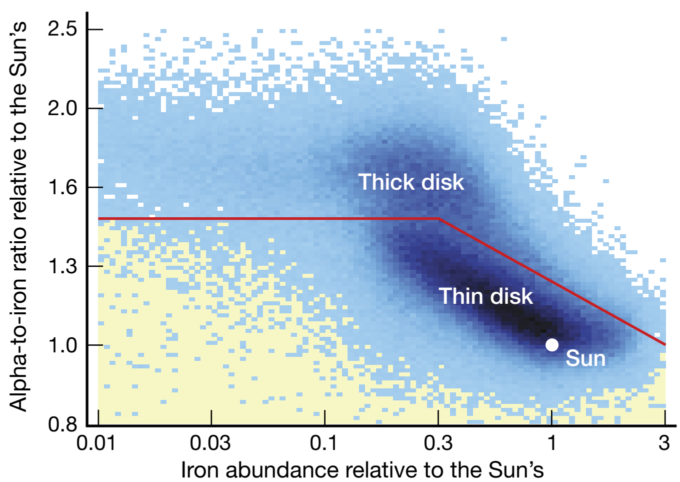
In contrast, these same massive stars didn't give the galaxy that much iron. Iron is the end of the line for a massive star: Once a star makes iron, the party is over, and the star dies. Most of the iron sits at the star's center, trapped in the neutron star or black hole that forms, and can't enrich the galaxy during the supernova. Thus, new stars that arose from this material had high alpha-to-iron ratios.

However, as time went on, another type of supernova appeared. These explosions came from white dwarfs, the former cores of red giants, and forged iron — including most of the iron in your blood. So when white dwarfs began to explode, the alpha-to-iron ratio fell.

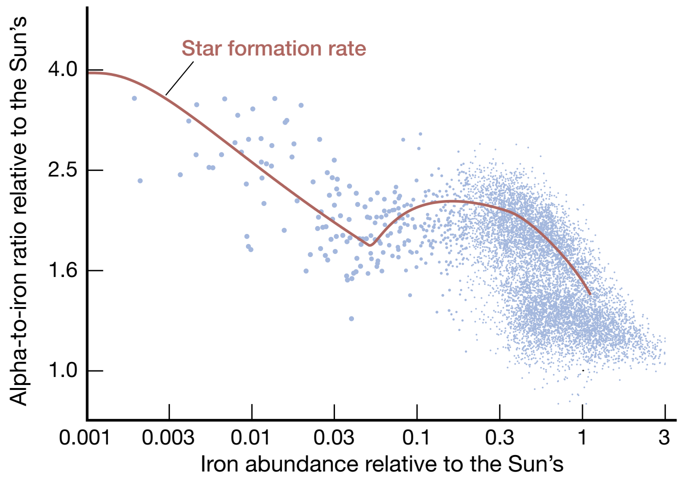
In a galaxy rapidly spawning stars, the alpha-to-iron ratio stays high, because white dwarfs don't have time to explode and produce iron before more stars spring up. In contrast, in a slow-paced galaxy, iron easily enriches the star-forming gas, so the alpha-to-iron ratio is lower.

Conroy's team saw that at the earliest times, as iron levels in stars rose from 0.3% of the Sun's value to 5% solar, their alpha-to-iron ratios fell. Then, some 13 billion years ago, the alpha-to-iron ratios began to rise, signifying much more intense star formation and the "phase transition" when Conroy says the thick disk originated. Billions of years later, after the iron level reached 20% solar, the alpha-to-iron ratio began to fall again.

What caused the metamorphosis 13 billion years ago that marked the birth of the thick disk and the start of such



▲ **STARS OF THE MILKY WAY** The thin disk of our galaxy formed slowly, so its stars — including the Sun — have low alpha-to-iron ratios. The thick disk, on the other hand, formed faster, so its stars have enhanced amounts of alpha elements such as oxygen, magnesium, and calcium.



▲ **STARS' RISE AND FALL** Through the course of the Milky Way's early history (as measured by stars' iron levels), the alpha-to-iron ratio first fell, then rose, then fell again. The period during which alpha elements became more abundant marked intense star formation. This period began abruptly some 13 billion years ago, when stars' typical iron-to-hydrogen ratio was only 5% solar, and continued until about 8 billion years ago, by which time metallicities had increased substantially.

vigorous star formation? "That's the million-dollar question," Conroy says. "We really don't know." Simulations of galaxy formation suggest that spiral galaxies usually form their first disks much later than this. Thus, the Milky Way may have been an early bloomer.

The Galaxy Gets Its Stellar Halo

The Milky Way has more than just a disk. It also has a halo — two halos, in fact. One is the dark matter halo, which emits no light, engulfs the thin and thick disks, outweighs all else in the Milky Way, and stretches nearly halfway to the Andromeda Galaxy. The second is the stellar halo, which consists of old, metal-poor stars and globular star clusters. Whereas most of the dark halo lies farther from the galaxy's center than the Sun does, most of the stars in the stellar halo lie closer to the galaxy's center than we do. That's why you see so many globular clusters in Sagittarius, Scorpius, and Ophiuchus, because these constellations are located in and around the galactic center.

The Milky Way wasn't born with its stellar halo; that came later. In 2018, two research teams — one led by Belokurov, the other by Amina Helmi (University of Groningen, The Netherlands) — used Gaia data to independently discover the source of most of the stellar halo: A smaller galaxy hit us long ago and splattered its own stars around the thick disk (*S&T:* Mar. 2020, p. 34).

Smaller galaxies have fewer metal-making stars than larger galaxies and therefore have lower metallicities. That's why the Milky Way's stellar halo is metal-poor: not because it's the oldest component, but because most of it came from that single smaller galaxy, whose metallicity was low. Still smaller galaxies have also hit the Milky Way, further augmenting the stellar halo and sprinkling it with streams of stars.

The ancient collision also splashed some of the stars then in the thick disk up into the halo. These "splash" stars, as Belokurov calls them, stand out from genuine halo stars because although they reside in the halo, they possess the higher metallicities of the thick disk. They are *in* the halo but not *of* the halo.

Exactly when this great halo-producing collision occurred is in dispute. Xiang and Rix say 11 billion years ago. "We found a peak in the star-forming rate at 11 billion years," Xiang says. "That means most of the thick-disk stars were actually formed at 11 billion years, with a burst." He says the rash of starbirth in the thick disk resulted because the collision drove gas clouds into one another, causing them to collapse and spawn new stars.

In addition, Xiang says, "All the splash stars are older than 11 billion years." Since the only stars that the collision kicked out of the thick disk were those that had already been born, this confirms the date of the collision, he argues.

But Conroy believes the collision occurred more recently, about 8 billion years ago. "Measuring ages is very hard," he says. If he's right, then the great halo-producing collision marked not the height of the thick-disk era but its end. Belokurov, for his part, thinks both teams are right: The merger started 10 to 11 billion years ago and concluded 8 to 9 billion years ago.

Either way, the researchers agree that the thick disk ran out of gas some 8 billion years ago, and the galaxy entered a new age.

The Thin-Disk Era

The thin disk started creating stars around 8 billion years ago after fresh gas, lower in metals, fell into the galaxy. The first of the thin-disk stars were therefore born with fewer metals than the last of the thick-disk stars. The thin disk formed stars more slowly than the thick disk did, so thin-disk stars — such as our 4.6-billion-year-old Sun — have lower alpha-to-iron ratios.

"It's been a pretty quiet place here for the past 8 or so billion years," Conroy says, and Xiang agrees. No substantial galaxies have crashed into our own. Indeed, the brightest victim to fall prey to the Milky Way during this time is the Sagittarius dwarf spheroidal, which our galaxy is currently tearing apart. That again makes us different from many other large spirals, including our good neighbor Andromeda.

Speaking of which: The future should be much livelier, for the giant Andromeda Galaxy is heading our way. Imagine astronomers 10 billion years hence, somewhere in the combined Andromeda–Milky Way Galaxy, trying to reconstruct that cataclysm . . . .

■ **KEN CROSWELL** earned his PhD from Harvard University for observing the Milky Way's stellar halo. He is the author of a book about the galaxy entitled *The Alchemy of the Heavens: Searching for Meaning in the Milky Way*.

OBSERVING
August 2023

3 MORNING: If you're up during the wee hours before dawn, face south-southwest to see the waning gibbous Moon hanging some 3½° below Saturn. Go to page 46 for more on this and other events listed here.

8 MORNING: The last-quarter Moon and Jupiter are a bit less than 2° apart high in the southeast.

9 MORNING: Look toward the east to take in the sight of the Moon gleaming about 2° right of the Pleiades. Jupiter completes the tableau farther to the upper right.

10 DUSK: Mercury and Mars sink in the west in tandem after sunset; some 5° separates the two worlds. To enjoy this view, you'll have to find an unobstructed horizon and bring binoculars.

11 MORNING: Face east-northeast to see the waning crescent Moon rise between the stars that mark the horns of Taurus, the Bull.

12–13 ALL NIGHT: The Perseid meteor shower reaches maximum. This is an exceptionally long shower so start looking for meteors anytime after mid-July. Turn to page 48 for the full story.

13 MORNING: The thin lunar crescent forms a triangle in the east-northeast with Gemini's bright lights, Castor and Pollux.

18 DUSK: The waxing crescent Moon and Mars are less than 1° apart low above the western horizon. Binoculars will tease the duo out of deepening twilight.

20 DUSK: Low in the west-southwest the slightly older lunar crescent is in Virgo a bit less than 6° right of Spica.

24 EVENING: The first-quarter Moon eclipses Antares, the red supergiant in Scorpius, for much of the U.S., southern Canada, and northernmost Mexico (see page 49). Face south-southwest to enjoy this sight.

30 EVENING: The full Moon and Saturn climb above the southeastern horizon with around 5° between them.
—DIANA HANNIKAINEN

▲ The annual Perseid meteor shower is a much-anticipated celestial event enjoyed by many. The image is a composite of exposures selected from more than 3,700 shots on the night of August 11–12, 2020, and shows 101 Perseids and 22 sporadics, i.e., meteors not associated with the Perseid shower. The base photo is the one that contains the bright fireball above and right of the San Francisco Peaks. JEREMY PEREZ

AUGUST 2023 OBSERVING
Lunar Almanac
Northern Hemisphere Sky Chart

Yellow dots indicate which part of the Moon's limb is tipped the most toward Earth by libration.
NASA / LRO

MOON PHASES

SUN	MON	TUE	WED	THU	FRI	SAT
		1	2	3	4	5
6	7	8	9	10	11	12
13	14	15	16	17	18	19
20	21	22	23	24	25	26
27	28	29	30	31		

FULL MOON
August 1
18:32 UT

LAST QUARTER
August 8
10:28 UT

NEW MOON
August 16
09:38 UT

FIRST QUARTER
August 24
09:57 UT

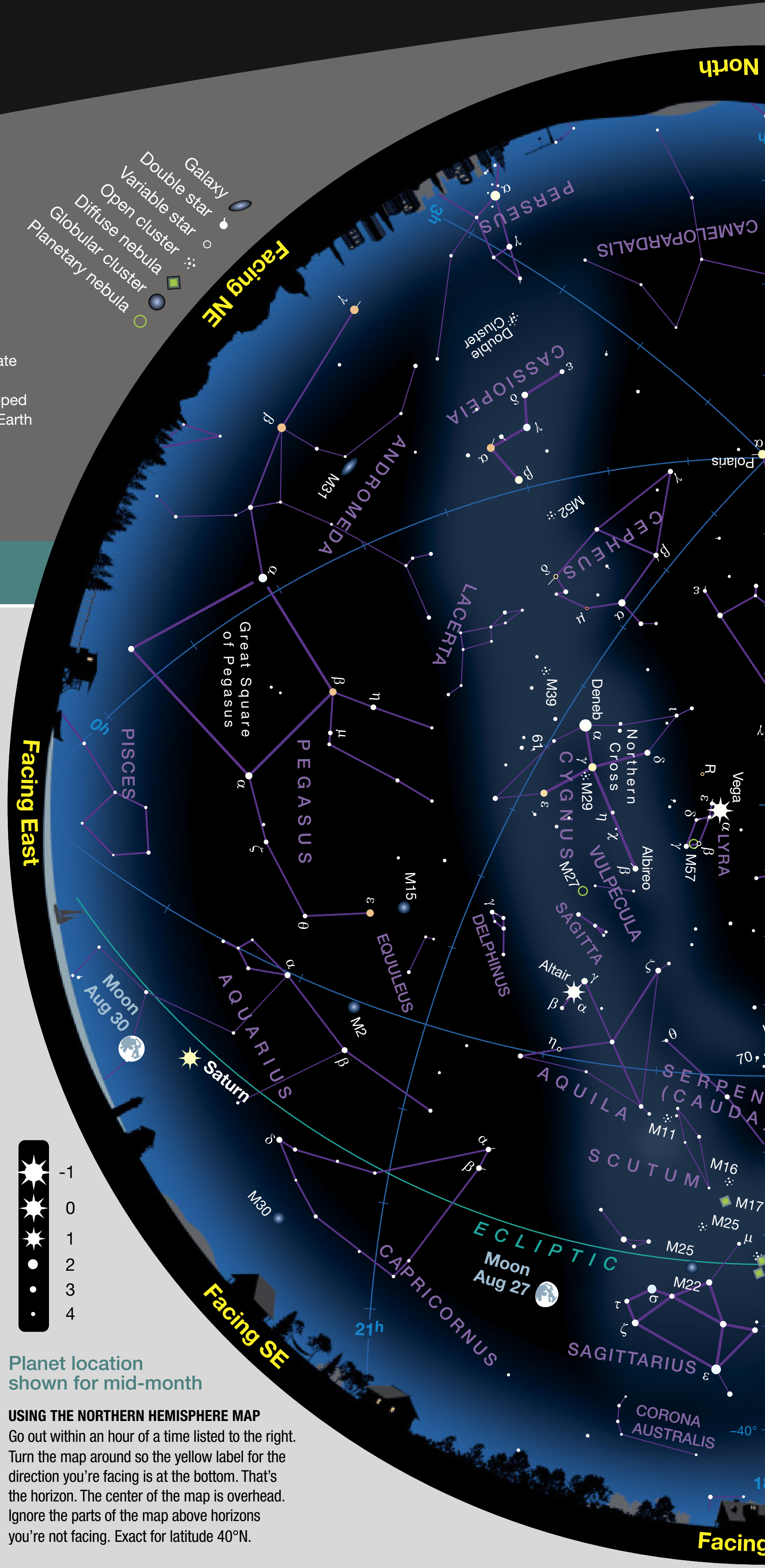
FULL MOON
August 31
01:36 UT

DISTANCES

Perigee 357,312 km	August 2, 06^h UT Diameter 33′ 26″
Apogee 406,634 km	August 16, 12^h UT Diameter 29′ 23″
Perigee 357,182 km	August 30, 16^h UT Diameter 33′ 27″

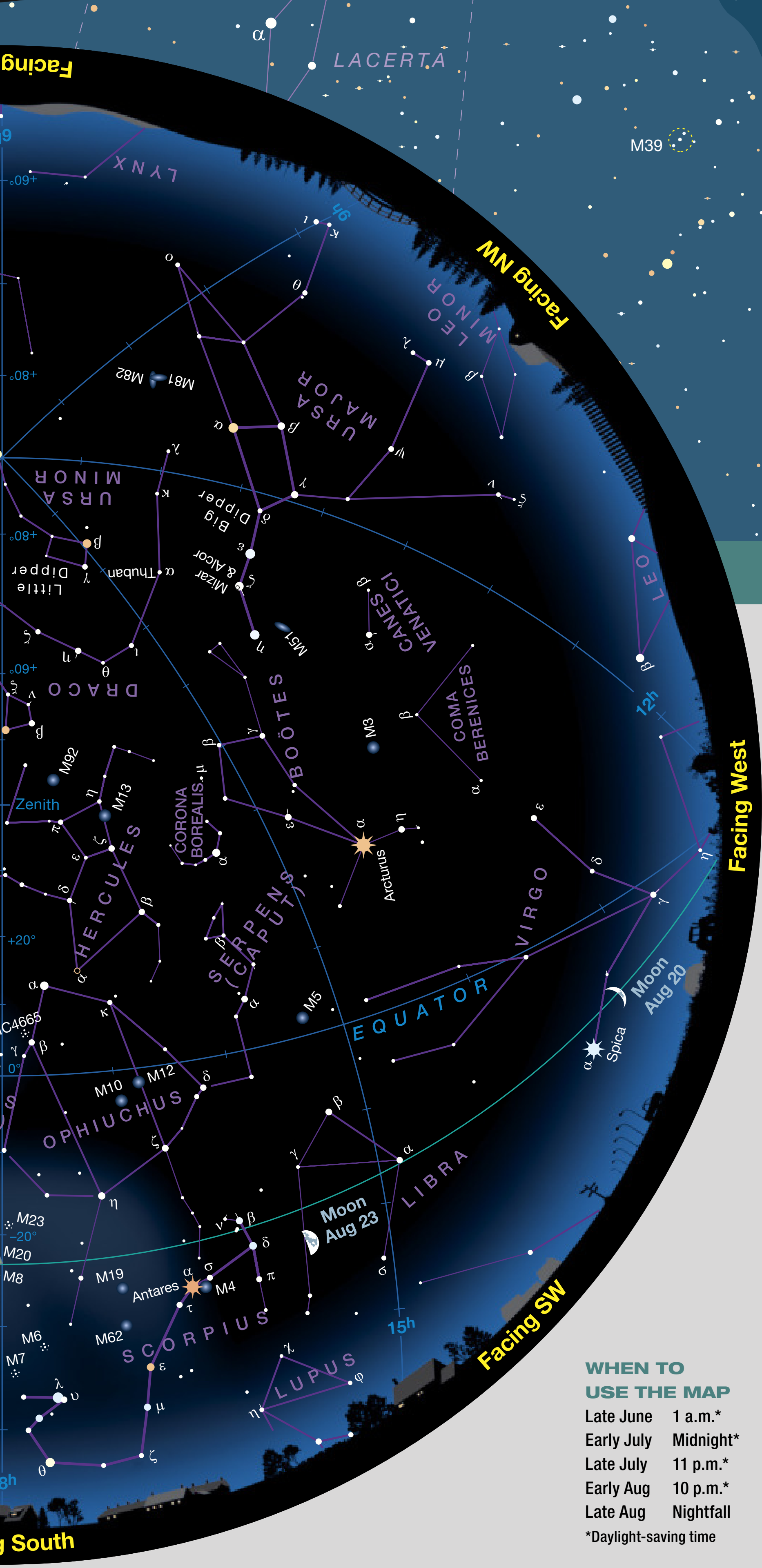
FAVORABLE LIBRATIONS

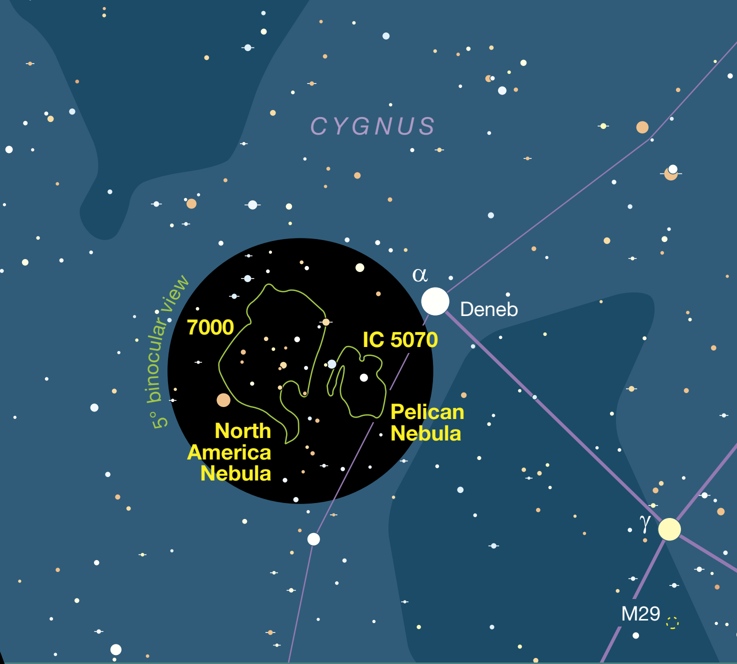
• Pythagoras Crater	August 1
• Mouchez Crater	August 2
• Anaximenes Crater	August 30
• Petermann Crater	August 31



Planet location shown for mid-month

USING THE NORTHERN HEMISPHERE MAP
Go out within an hour of a time listed to the right. Turn the map around so the yellow label for the direction you're facing is at the bottom. That's the horizon. The center of the map is overhead. Ignore the parts of the map above horizons you're not facing. Exact for latitude 40°N.





WHEN TO USE THE MAP

Late June	1 a.m.*
Early July	Midnight*
Late July	11 p.m.*
Early Aug	10 p.m.*
Late Aug	Nightfall

*Daylight-saving time

Binocular Highlight by Mathew Wedel

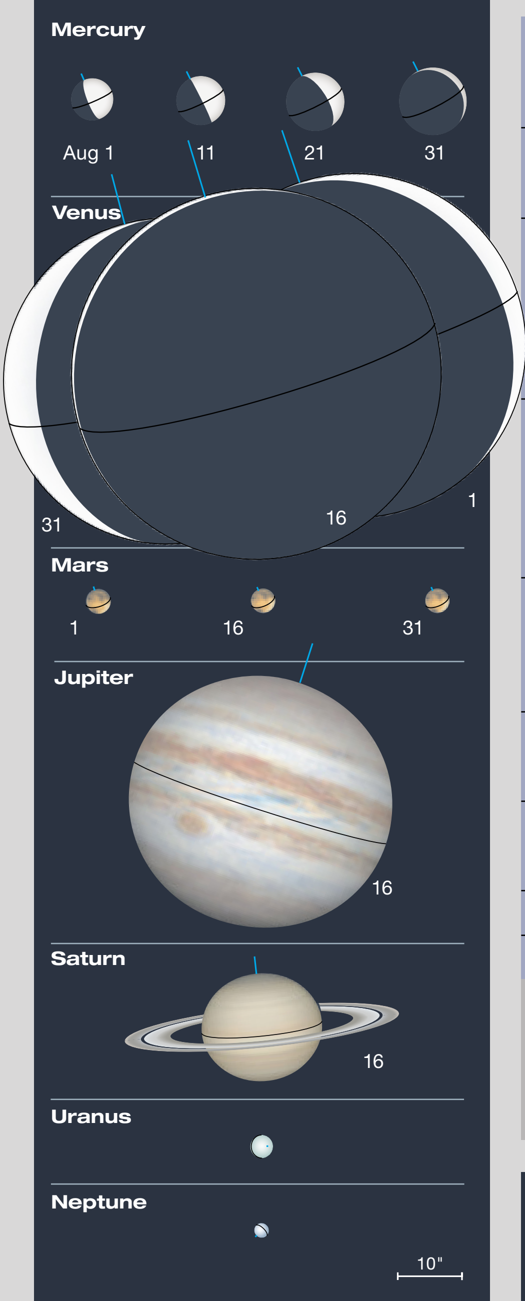
Giant of the North

Our target this month is the **North America Nebula** (NGC 7000, Caldwell 20) in the constellation Cygnus, the Swan. William Herschel first recorded its pale glow in 1786, while his son, John, cataloged it in 1829. It didn't get its familiar name until 1903, when E. E. Barnard refined German astrophotographer Max Wolf's original designation, the "America Nebula," to reflect more accurately the object's resemblance to its namesake continent.

Photos of NGC 7000 go deeper than the binocular-boosted eye, of course, but that adds to the challenge: We know how much there is to be seen, and it's fun to push ourselves to see as much as possible. Located just 3° east of Deneb, or Alpha (α) Cygni, it's an easy catch at 4th magnitude even with 7×35 binos (despite its low surface brightness). But drawing out its true "North-America-ness" generally requires more aperture. In particular, I need at least 15×70s to catch the portion of the nebula that corresponds to Florida. Equally challenging is the **Pelican Nebula** (IC 5070), which rears from the dark Atlantic like a lost continent. Their appearance as distinct objects is an illusion — the North America and Pelican nebulae are just the visible parts of a single, vast hydrogen cloud, only separated from our point of view by a dark lane of dust in the foreground (designated LDN 935).

Historical distance estimates for NGC 7000 ranged from 1,500 to 3,000 light-years. In 2020, the European Space Agency's Gaia spacecraft measured the distances to 395 stars embedded in the nebula, yielding an average of 2,590 light-years. This places it about twice as far away as M42, the Great Nebula in Orion, and makes it much, much larger. How much of this vast, remote giant will you capture?

■ No matter which binos he's using, **MATT WEDEL** enjoys pushing them to see as much as he can.



▲ **PLANET DISKS** are presented north up and with celestial west to the right. Blue ticks indicate the pole currently tilted toward Earth.

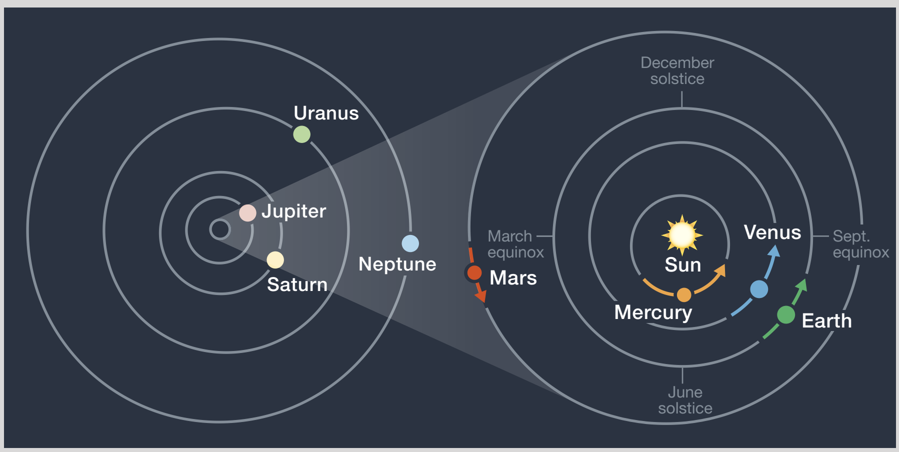
▶ **ORBITS OF THE PLANETS** The curved arrows show each planet's movement during August. The outer planets don't change position enough in a month to notice at this scale.

PLANET VISIBILITY (40°N, naked-eye, approximate) **Mercury** visible at dusk until the 10th • **Venus** visible at dawn starting on the 20th • **Mars** visible at dusk to the 20th • **Jupiter** rises around midnight and visible until sunrise • **Saturn** rises around sunset and transits before dawn.

August Sun & Planets

	Date	Right Ascension	Declination	Elongation	Magnitude	Diameter	Illumination	Distance
Sun	1	$8^h\ 42.5^m$	+18° 13′	—	–26.8	31′ 31″	—	1.015
	31	$10^h\ 35.0^m$	+8° 56′	—	–26.8	31′ 41″	—	1.010
Mercury	1	$10^h\ 23.1^m$	+9° 59′	26° Ev	0.0	6.6″	62%	1.023
	11	$11^h\ 02.3^m$	+4° 10′	27° Ev	+0.3	7.7″	48%	0.878
	21	$11^h\ 21.8^m$	+0° 10′	24° Ev	+0.8	9.1″	29%	0.738
	31	$11^h\ 12.6^m$	+0° 11′	13° Ev	+2.9	10.5″	8%	0.638
Venus	1	$9^h\ 48.1^m$	+7° 26′	19° Ev	–4.3	53.5″	6%	0.312
	11	$9^h\ 26.6^m$	+7° 17′	8° Ev	–4.1	57.6″	1%	0.290
	21	$9^h\ 03.1^m$	+8° 23′	14° Mo	–4.2	56.2″	3%	0.297
	31	$8^h\ 50.2^m$	+9° 55′	26° Mo	–4.6	50.6″	10%	0.330
Mars	1	$10^h\ 58.4^m$	+7° 34′	35° Ev	+1.8	3.9″	97%	2.376
	16	$11^h\ 33.0^m$	+3° 46′	30° Ev	+1.8	3.8″	98%	2.437
	31	$12^h\ 08.0^m$	–0° 09′	25° Ev	+1.8	3.8″	98%	2.485
Jupiter	1	$2^h\ 45.1^m$	+14° 41′	85° Mo	–2.4	39.8″	99%	4.949
	31	$2^h\ 52.6^m$	+15° 08′	112° Mo	–2.6	43.8″	99%	4.501
Saturn	1	$22^h\ 31.4^m$	–11° 09′	153° Mo	+0.6	18.7″	100%	8.867
	31	$22^h\ 23.3^m$	–11° 59′	176° Ev	+0.4	19.0″	100%	8.765
Uranus	16	$3^h\ 21.4^m$	+18° 08′	90° Mo	+5.7	3.6″	100%	19.611
Neptune	16	$23^h\ 50.3^m$	–2° 25′	146° Mo	+7.8	2.3″	100%	29.065

The table above gives each object's right ascension and declination (equinox 2000.0) at 0^h Universal Time on selected dates, and its elongation from the Sun in the morning (Mo) or evening (Ev) sky. Next are the visual magnitude and equatorial diameter. (Saturn's ring extent is 2.27 times its equatorial diameter.) Last are the percentage of a planet's disk illuminated by the Sun and the distance from Earth in astronomical units. (Based on the mean Earth–Sun distance, 1 a.u. equals 149,597,871 kilometers, or 92,955,807 international miles.) For other timely information about the planets, visit **skyandtelescope.org**.



Southern Scorpius

Some of the celestial Scorpion's finest sights skim the horizon.

Last month I took a look at the northern half of the giant curl of bright stars that is Scorpius, the Scorpion. This time we're going to dive down into the constellation's southerly half — a region brimming with wonders.

I'll begin by begging for the indulgence of our readers north of 50° latitude since southernmost Scorpius is simply out of reach. However, anyone viewing the sky south of around latitude 40° north can see this section of the Scorpion fairly well, especially on summer nights free from low-lying haze.

Let's start our tour with the two bright and close stars that together form the tip of the Scorpion's stinger: 1.6-magnitude Lambda (λ) Scorpii (Shaula) and 2.7-magnitude Upsilon (υ) Scorpii (Lesath). They're sometimes known as the Cat's Eyes, though one eye is much brighter than the other. Every summer I watch the pair's progress across my southern sky, leading the way for the Teapot of Sagittarius. Shaula and Lesath are only 36′ apart; having two bright stars apparently so close together is very rare. Shaula is the 24th brightest star in all the heavens, falling just ever so slightly short of being a 1st-magnitude star.

Just a binocular field of view away from this stellar duo is a pair of big and bright naked-eye open star clusters, M6 and M7. Both were recorded in ancient times by Ptolemy, and even now M7 is often referred to as Ptolemy's Cluster. Just 3½° separates the two clusters — M6 is 33′ across and glows at a total magnitude of 4.2, while neighboring M7 is a whopping 75′ wide and listed at a magnitude of 3.3. But well-known observer Stephen James O'Meara has estimated M7's total brightness to be 2.8 and regards the cluster as the single brightest spot of light in the naked-eye Milky Way. The cluster contains eight stars brighter than 6.5 and several dozen brighter than 9.0. It's a wonderful binocular object, whereas M6 is best enjoyed in a telescope where the pattern of some of its brightest stars has earned it the nickname Butterfly Cluster. Interestingly, M7 is about 900 light-years away from Earth, about half as far as M6. If they were instead at the same distance, they'd essentially be cluster twins.

Let's end our tour of Scorpius in the north-south line of stars that includes Epsilon (ε), Mu (μ), and Zeta (ζ) Scorpii. This region contains much that requires optical aid to enjoy, but also some notable naked-eye wonders. First, there's NGC 6231, an open cluster that concentrates a brightness of magnitude 2.6 into an area 14′ across. According to author Robert Burnham, Jr., if NGC 6231 were as close as the Pleiades, it would appear roughly the same size but shine with stars as bright as Sirius!

Another attraction in this part of Scorpius is the pair of suns comprising Mu Scorpii. The stars are wide enough apart (less than 350″) that sharp eyes can split them. They were known in Polynesian legends as "the Inseparables" — two children fleeing their evil parents. Mu^1 varies in brightness from magnitude 2.9 to 3.2, while Mu^2 shines at 3.6. A bit more than 4° south-southeast of Mu is another pair, Zeta^1 and Zeta^2, which are separated by nearly 400″ and shine at magnitudes 4.7 and 3.6, respectively. What's more, Zeta^2 is 132 light-years from us while Zeta^1 may be as distant as 2,500 light-years, making it one of the most distant and luminous of all naked-eye stars.

The main pattern of Scorpius curves back up to the stinger forming the fishhook of the Polynesian god Maui, who was said to have used the hook to lift several of the beautiful islands up from the sea. Given all the treasures found in the constellation, the tale doesn't seem all that fanciful!

■ **FRED SCHAAF** sometimes dreams of Scorpius and the center of the Milky Way crossing the zenith somewhere in Australia or New Zealand.

GARY SERONIK

▲ **STELLAR SCORPION** The fishhook form of Scorpius skims the southern horizon on August evenings as seen from mid-northern latitudes. From locations farther south, such as Costa Rica (where this photo was captured), Australia, or New Zealand, the constellation is truly wondrous and among the most striking in the entire night sky.

To find out what's visible in the sky from your location, go to skyandtelescope.org.

The Red Planet's Farewell

Mars encounters both Mercury and the Moon before slipping away.

THURSDAY, AUGUST 3

Early risers will be greeted at dawn by the sight of the waning gibbous **Moon** parked just 3° below **Saturn**, high in the south-southwest. They're at their very closest (2.3° apart) at 6:52 PDT, but that will be during full daylight for observers across North America. Suffice it to say, the later in the morning you look and the farther west you are, the smaller the gap between the two objects will be.

August is a big month for the Ringed Planet as it reaches *opposition* (appears opposite the Sun in the sky) on the 27th. Around opposition, Saturn rises at sunset and is visible all night long. (Turn to page 50 for more.) The planet is also at its brightest during opposition, this time glowing at magnitude +0.4. Mind you, Saturn doesn't undergo the same kind of dramatic brightness swings that other planets do. Even at its faintest, earlier this year, it still managed to reach magnitude +1.0.

TUESDAY, AUGUST 8

Jupiter and the **Moon** have been holding regular monthly meetings since the big planet emerged from its conjunction with the Sun back in April. This morning, the last-quarter Moon sits just a bit more than 1½° above the –2.4-magnitude planet in the southeast at 2:30 a.m. EDT. This one is worth getting up early (or staying up late) for since it's the year's last close conjunction between the pair.

Indeed, you'll have to wait until October 2026 for another chance to see them this close together at night. Although the Moon returns to the same location in the sky every 27.3 days (what is known as a *sidereal month*), its elliptical path around Earth is inclined by about 5°, which means that on each subsequent return, its position is shifted slightly north or south compared to the previous passage. And, of course, Jupiter is moving along in its orbit at the same time. As a result of all this, we tend to get a series of close passes, followed by a series of increasingly distant ones. Further complicating the situation is the fact that the Moon and Jupiter might appear closest when they're below the horizon and out of view, or when they're too near the Sun to safely observe. So be sure to set your alarm for this morning!

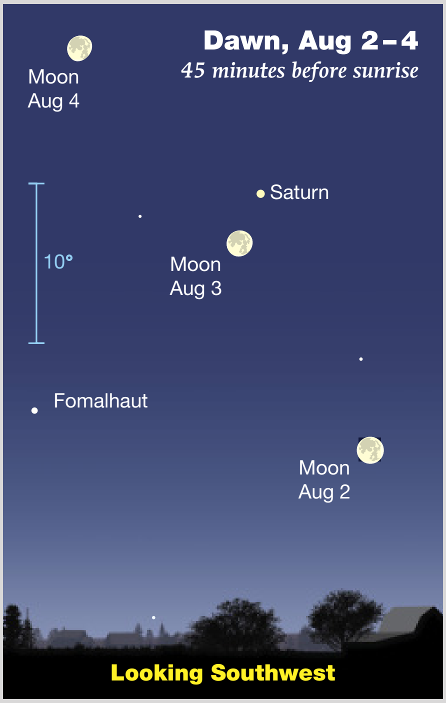
THURSDAY, AUGUST 10

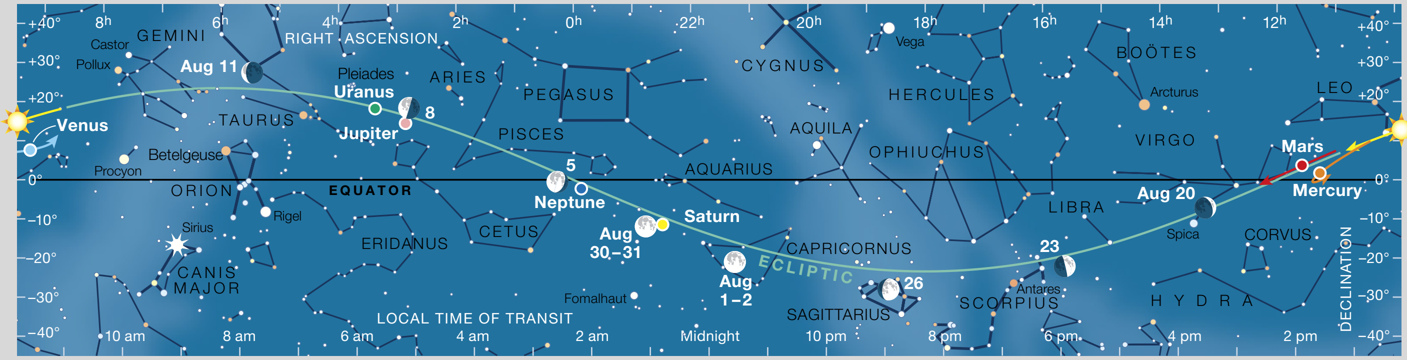
If your observing site offers an unobstructed view towards the west, you have a golden opportunity to watch a pair of planets close together at dusk. The two players in this mini-drama are **Mars** and **Mercury**. Starting this evening (and continuing until the 16th), the solar system's two smallest planets will be separated in the sky by less than 5°. That means you'll be able to view them together in typical binoculars.

Although it might seem like you have plenty of time to enjoy this pairing, don't dally — each night the planets sink a little lower and Mercury fades a little more. As it is, this evening Mercury (the lower of the twosome) is just 6° up half an hour after sunset. The innermost planet reached greatest elongation on the 9th, but this is its least favorable evening apparition of the year. If Mercury eludes you this time around, you'll have another, better chance of catching it at dawn in September and again at dusk in December.

FRIDAY, AUGUST 18

Mars is at the end of its current showing. In fact, this might be the last time you see it for a while. As a naked-eye sight, the Red Planet will soon be lost in the Sun's glare. And yet it won't have its solar conjunction for another three months! But at dusk tonight Mars has a last hurrah when a very thin (6%-illuminated) crescent **Moon** pays a visit. That wiry crescent will be your key to locating the planet as twilight dims. Use your binoculars and look about two Moon diameters (roughly 1°) to the lower left of the crescent for the 1.8-magnitude ember that is Mars. Begin your search early, however, as the Moon is only 10° above the western horizon 30 minutes after sunset. Despite the difficulty, the effort is





▲ The Sun and planets are positioned for mid-August; the colored arrows show the motion of each during the month. The Moon is plotted for evening dates in the Americas when it's waxing (right side illuminated) or full, and for morning dates when it's waning (left side illuminated). "Local time of transit" tells when (in Local Mean Time) objects cross the meridian — that is, when they appear due south and at their highest — at mid-month. Transits occur an hour later on the 1st and an hour earlier at month's end.

worthwhile. Mars won't re-emerge until next March when it shows up in morning twilight. That's a long time to wait!

THURSDAY, AUGUST 24

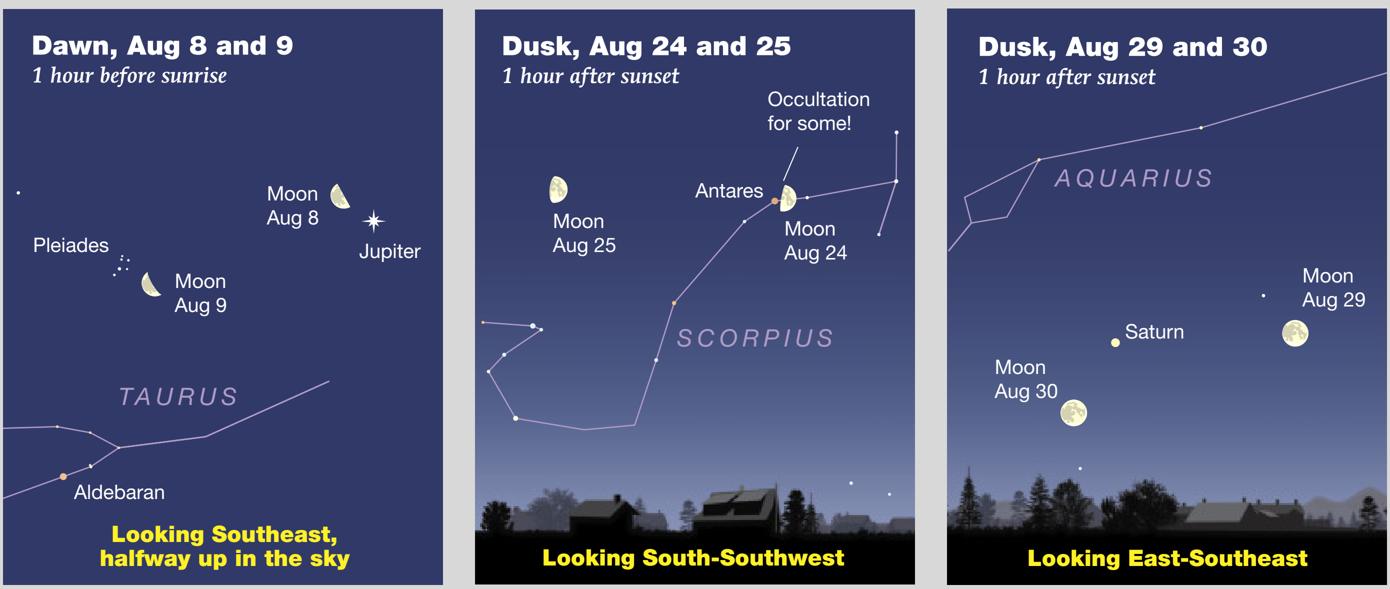
This evening, the **Moon** is very, very close to **Antares** in Scorpius. In fact, for much of the U.S., Canada, and northern Mexico, the dark limb of the Moon actually eclipses the 1st-magnitude star. This event is covered in much more detail on page 49, so here we'll just note that part of the fun is using binoculars or your unaided eyes to watch the Moon slowly approach Antares. When the star blinks out, it does so instantaneously. The sight never fails to impress — especially when it's a star as bright as this one, and it's the dark limb of the Moon that does the covering. The reappearance is far less dramatic, but certainly worth sticking around for.

WEDNESDAY, AUGUST 30

As twilight begins to fade after sunset, look to the east-southeast to catch the full **Moon** rising along with **Saturn**, which is some 5° above and to the right. This conjunction is notable for a couple of reasons. First, this is the closest full Moon of the year, so you can expect lots of talk about a "supermoon." Astronomers, however, refer to this as a "perigean full Moon," that is, a full Moon occurring when the Moon is at *perigee* — its closest approach to Earth during its monthly trip around our planet. Second, Saturn is just three days past opposition, which is why the Moon is nearby. You can think of the full Moon as our satellite's "opposition" since it lies opposite the Sun's position in the sky, with Earth in between. To put it another way, consider that if you drew a line from the Sun, through Earth and continued it onwards, the line would bring you to the Moon and then, much farther out, to Saturn and beyond. From our earthbound perspective, the two objects simply appear in the same patch of sky.

■ Consulting Editor **GARY SERONIK** thinks every full Moon is "super."

◀▼ These scenes are drawn for near the middle of North America (latitude 40° north, longitude 90° west). European observers should move each Moon symbol a quarter of the way toward the one for the previous date; in the Far East, move the Moon halfway.



Moon Bows Out for the Perseids

Conditions are nearly ideal for the summer's best meteor shower.

The timing for this year's Perseid meteor shower is almost as good as it gets. The peak is expected on the morning of August 13th, and for a change the Moon will not be a concern. Instead of dashing hopes, the 8%-illuminated crescent will provide a fitting coda, rising an hour and a half before the start of astronomical twilight.

Observers blessed with dark skies may see up to 90 meteors per hour. Your results will vary, depending on the amount of local light pollution and when you choose to watch. I live on the outskirts of a moderate-size city that floods much of the southern sky with artificial light. At best I've bagged 40 Perseids in an hour, more than enough for a fulfilling experience.

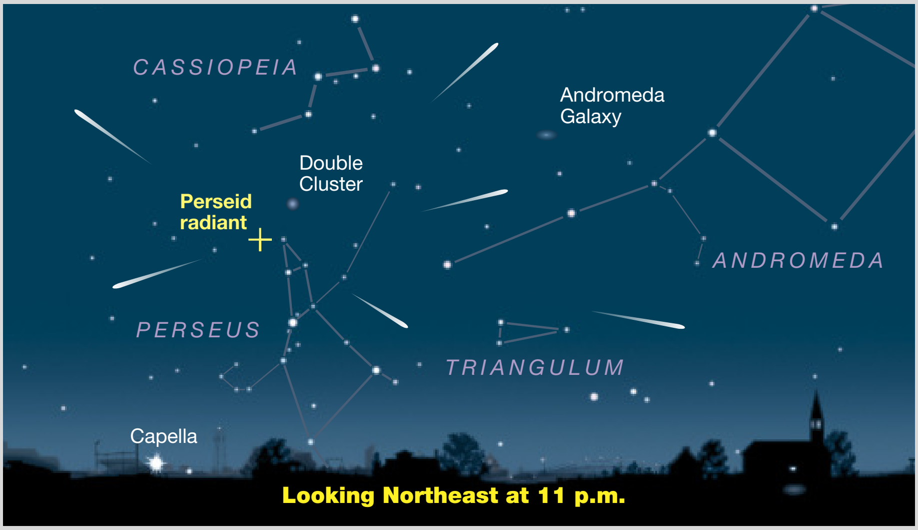
If you're prepared to seek dark skies, consult the interactive light pollution map at **lightpollutionmap.info**. With your mouse, drag the center of the map to your desired location, then use the scroll wheel to zoom in. Areas color-coded in purple, red, and yellow are overrun with artificial illumination, while those in blue and gray are dark and conducive to meteor watching. Click anywhere on the map for details about a particular site, including its Bortle sky-brightness classification.

Data from NASA's All Sky Fireball Network reveal that the Perseids blast out more *fireballs* (meteors of magnitude –3 or brighter) than any other shower. This may be due to the jumbo-size nucleus of the shower's parent, Comet Swift-Tuttle. At 26 km (16 mi) across, it's more than three times larger than Halley's Comet. Big comets typically release more material than smaller ones, and many of the fragments are weighty enough to spawn brilliant meteors.

Earth crosses Swift-Tuttle's debris trail starting in mid-July and exits around September 1st. The Perseid peak occurs when we enter the densest part of that stream in mid-August. Although we call the Perseids a shower, they're more like an intermittent drizzle. Distances between individual particles range from 96 to 160 km — a span that would take more than an hour to drive at freeway speeds.

The smallest bits of debris are the size of sand grains and scratch out modest flashes. Larger ones are pebble-size, weighing a few grams, and create more impressive streaks. Perseids strike the atmosphere at more than 200,000 km/h and pack a considerable kinetic punch. Impact and deceleration both

◀ Astrophotographer Petr Horálek made this composite self-portrait at Seč Lake in the Iron Mountains of the Czech Republic during the 2020 Perseids. He captured 109 meteors over four nights in a series of 30-second exposures shot with a modified Canon EOS 6D camera and Samyang 12-mm, f/2.8 lens. This month the Perseid meteor shower peaks on the night of August 12–13 under a mostly moonless sky.



ablate the meteoroid and etch a bright trail of energized atmospheric gases that make the bright flash of light we see. Such streaks typically last about one second, and though they measure less than 1 meter (3 ft) across, they can stretch for tens of kilometers.

A 2020 report based on photographs made by the Tajikistan fireball network from 2007 to 2011 determined that the 29 Perseid fireballs recorded had masses of up to 20 grams (0.7 oz), while a 1997 study of two Perseids of magnitude –11 yielded masses of 40 g and 80 g each. Perseid spectra display lines of calcium, magnesium, sodium, silicon, and iron that match well with the composition of carbonaceous chondrite (CC) meteorites. Given that CCs are often fragile, it's not surprising that no known Swift-Tuttle fragments have survived atmospheric entry. But, as noted in the June issue (page 50), vaporized comet crumbs producing a "soot" serve as condensation nuclei for the formation of noctilucent clouds in Earth's mesosphere.

Although the shower climaxes during the early morning hours of the 13th, it's worth starting your watch at nightfall on the 12th, around 9:30 to 10:00 p.m. local daylight time. Meteor numbers will be lower at that time because the *radiant* (the point from which the meteors appear to stream) in the constellation Perseus sits low in the northeastern sky. However, if you have children and want to get them to bed at a reasonable hour, an evening session is still worthwhile. Set out reclining chairs and face east or southeast. Be patient and you should see a few Perseids streak across the sky. Any time spent with children under the stars counts as quality time.

The later you stay up the higher the radiant climbs and the more meteors you'll be able to see. I like to observe for an hour or so late in the evening, then set the alarm for 2 a.m. and watch until dawn. In the morning hours, Perseus stands high in the northeastern sky, so face south or north (whichever direction is darkest where you live) and tip your recliner about 30° from horizontal. That way you'll be gazing up at higher altitudes where atmospheric dimming is least. Remember to bring a blanket — it's surprising how quickly an inactive body loses heat on a clear night, even in summer.

If you plan on photographing the event, use a tripod-mounted camera at ISO 1600 and equipped with an intervalometer set to take successive 30-second exposures. My default lens is a 16–35-mm zoom dialed in to about 20-mm, with the aperture wide open at f/2.8. If dew is a problem where you live, try rubber-banding a pair of chemical hand warmers around the top and bottom of the lens to keep the optics clear and dry.

As the camera automatically does its work, relax and enjoy a night of serenity and surprise — both of which you'll experience in equal measure during the Perseid meteor shower.

Antares Goes into Hiding

AS THE MOON weaves along the ecliptic, a quartet of 1st-magnitude stars potentially lie in its path: Regulus, Spica, Aldebaran, and Antares. Most recently the Moon hid Aldebaran in September 2018, so it's been a while. The drought comes to an end this month with the start of a series of Antares occultations. The first occurs on the evening of August 24th and is visible across much of North America, from Canada as far south as Mexico.

Disappearance occurs around 2^h UT on the 25th (10 p.m. EDT on the 24th) as the dark limb of the 57%-illuminated waxing gibbous Moon covers the star, though the time varies according to location. A table showing the times of disappearance and reappearance for many cities is presented by the International Occultation Timing Association at **https://is.gd/antaresoccultation**.

For observers in northern East Coast cities, the Moon is very low in the southwestern sky when it covers Antares and sets before the star reappears. Farther south along the coast, the Moon sits higher in the sky and both the disappearance and reappearance are visible. Some locations, including Gainesville, Florida, experience a grazing occultation, with Antares scraping along the Moon's southern limb.

Central and western states have the best views. Denverites will see the Moon cover the star shortly after sunset at 8:01:34 p.m. MDT and watch it pop back to life at 9:11:49 p.m. Unfortunately, the entire event takes place in late afternoon daylight for the West Coast.

Antares is a well-known, close double star with a 5.4-magnitude companion currently 2.6″ away nearly due west of the primary at a position angle of 277°. During the occultation the Moon covers the secondary first, followed moments later by the bright primary. Although the primary emerges first from behind the Moon's bright limb, glare will likely make it challenging to spot. I would love to hear if you see it though.

Saturn at Opposition

▲ The Hubble Space Telescope photographed Saturn on March 12, 2011, with its ring plane inclined 9.4° — nearly the same as at opposition this month.

WHETHER IT'S YOUR first time or 200th, Saturn is an irresistible telescopic sight. The planet brightens to magnitude +0.4 as it inches westward across central Aquarius. By opposition on August 27th, its globe spans 19.0″ and the rings extend to 43.1″. The most notable change compared to last year is the narrowing tilt of those rings. Tipped by just 9.0° at opposition, we view the north face of the rings. We'll continue to do so until March 2025, when they will be presented edge-on. A 60-mm (2.4-inch) telescope magnifying 40× will show the rings easily.

Saturn's diminishing tilt means it's difficult to observe the entire curve of the dark Cassini Division, which separates the A and B rings. However, the gap should still be easy to make out at the ansae of the rings in good seeing. Also, be sure to look for the translucent C ring (also known as the crepe ring). It appears interior to the B ring on either side of the planet.

Because Saturn's northern hemisphere is still tipped in our direction, the North Equatorial Belt, Equatorial Zone, pale North Tropical Zone, and dusky North Polar Region remain the easiest atmospheric features to see. To pick out these low-contrast belts and zones you'll need a 4- to 6-inch instrument.

Of the planet's 83 known satellites, Titan is the brightest and largest. At magnitude 8.6 and one and a half times the size of our own Moon, Titan is easily visible in the smallest of telescopes. Larger instruments will reveal several additional moons: Rhea (magnitude 9.8), Tethys (10.4), Dione (10.5), Enceladus (11.9), Mimas (13.0), and Hyperion (14.5). To find the bright moons at any time, use our interactive Saturn's Moons app, found on the Tools page at **skyandtelescope.org**.

Minima of Algol

Aug.	UT
2	8:14
5	5:03
8	1:51
10	22:40
13	19:29
16	16:17
19	13:06
22	9:54
25	6:43
28	3:32
31	0:20

These geocentric predictions are from the recent heliocentric elements Min. = JD 2457360.307 + 2.867351E, where E is any integer. They were derived by Roger W. Sinnott from 15 photoelectric series in the AAVSO database acquired during 2015–2020 by Wolfgang Vollmann, Gerard Samolyk, and Ivan Sergey. For a comparison-star chart and more info, see **skyandtelescope.org/algol**.

▲ Perseus approaches the zenith during pre-dawn hours in August. Every 2.7 days, Algol (Beta Persei) dips from its usual magnitude 2.1 to 3.4 and back. Use this chart to estimate its brightness in respect to comparison stars of magnitude 2.1 (Gamma Andromedae) and 3.4 (Alpha Trianguli).

Action at Jupiter

MILD AUGUST NIGHTS offer a fine opportunity to enjoy scoping the solar system's most visually rewarding planet, Jupiter. At mid-month it rises just a little before midnight (local daylight-saving time) and reaches the meridian shortly after sunset. That means the predawn hours are the best for enjoying the wondrous details that the planet has on offer. During August, Jupiter brightens slightly from magnitude –2.4 to –2.6, while its disk grows perceptibly from 39.8″ to 43.8″.

Any telescope reveals the four big Galilean moons, and binoculars usually show at least two or three. Use the diagram on the facing page to identify them by their relative positions on any given date and time. All the observable interactions between Jupiter and its satellites and their shadows are tabulated on the facing page.

Features on Jupiter appear closer to the central meridian than to the limb for 50 minutes before and after transiting. Here are the times, in Universal Time, when the Great Red Spot should cross Jupiter's central meridian. The dates, also in UT, are in bold. (Eastern Daylight Time is UT minus 4 hours.)

July 1: 6:08, 16:04; **2**: 2:00, 11:56, 21:51; **3**: 7:47, 17:43; **4**: 3:39, 13:34, 23:30; **5**: 9:26, 19:22; **6**: 5:17, 15:13; **7**: 1:09, 11:05, 21:00; **8**: 6:56, 16:52; **9**: 2:47, 12:43, 22:39; **10**: 8:35, 18:30; **11**: 4:26, 14:22; **12**: 0:18, 10:13, 20:09; **13**: 6:05, 16:01; **14**: 1:56, 11:52, 21:48; **15**: 7:43, 17:39; **16**: 3:35, 13:31, 23:26; **17**: 9:22, 19:18; **18**: 5:14, 15:09; **19**: 1:05, 11:01, 20:56; **20**: 6:52, 16:48; **21**: 2:44, 12:39, 22:35; **22**: 8:31, 18:26; **23**: 4:22, 14:18; **24**: 0:14, 10:09, 20:05; **25**: 6:01, 15:56; **26**: 1:52, 11:48, 21:44; **27**: 7:39, 17:35; **28**: 3:31, 13:26, 23:22; **29**: 9:18, 19:14; **30**: 5:09, 15:05; **31**: 1:01, 10:56, 20:52

August 1: 6:50, 16:45; **2**: 2:41, 12:37, 22:32; **3**: 8:28, 18:24; **4**: 4:20, 14:15; **5**: 0:11, 10:07, 20:02; **6**: 5:58, 15:54; **7**: 1:49, 11:45, 21:41; **8**: 7:36, 17:32; **9**: 3:28, 13:23, 23:19; **10**: 9:15, 19:11; **11**: 5:06, 15:02; **12**: 0:58, 10:53, 20:49; **13**: 6:45, 16:40; **14**: 2:36, 12:32, 22:27; **15**: 8:23, 18:19; **16**: 4:14, 14:10; **17**: 0:06, 10:01,

NASA / STSCI / TED STRYK

19:57; **18**: 5:53, 15:48; **19**: 1:44, 11:40, 21:35; **20**: 7:31, 17:27; **21**: 3:22, 13:18, 23:14; **22**: 9:09, 19:05; **23**: 5:01, 14:56; **24**: 0:52, 10:47, 20:43; **25**: 6:39, 16:34; **26**: 2:30, 12:26, 22:21; **27**: 8:17, 18:13; **28**: 4:08, 14:04; **29**: 0:00, 9:55, 19:51; **30**: 5:47, 15:42; **31:** 1:38, 11:33, 21:29

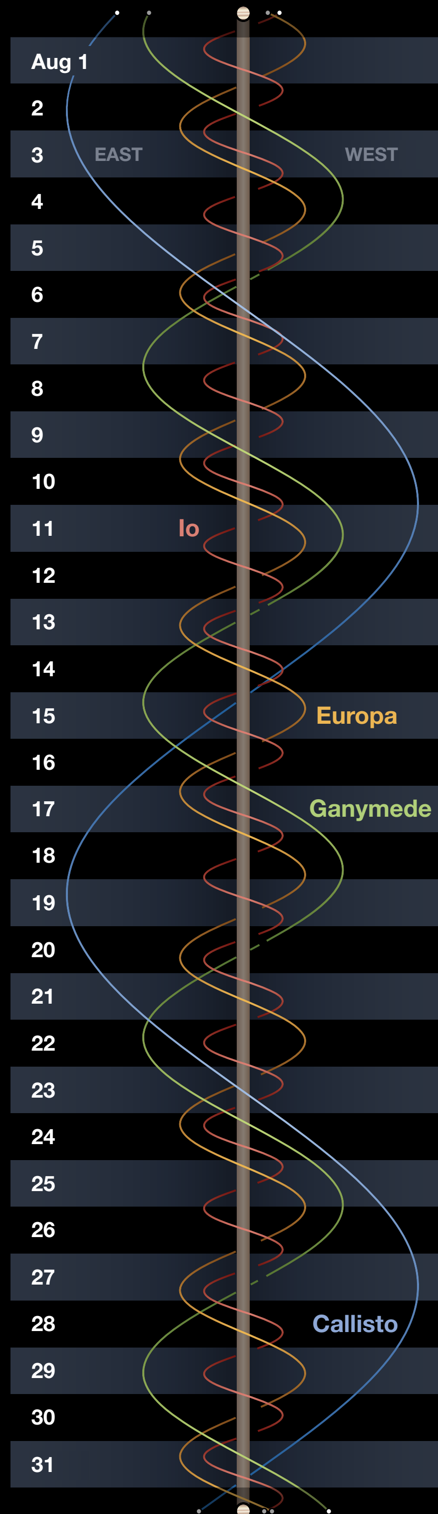
These times assume that the spot will be centered at System II longitude 42° on August 1st. If the Red Spot has moved elsewhere, it will transit $1\frac{2}{3}$ minutes earlier for each degree less than 42° and $1\frac{2}{3}$ minutes later for each degree more than 42°.

Phenomena of Jupiter's Moons, August 2023

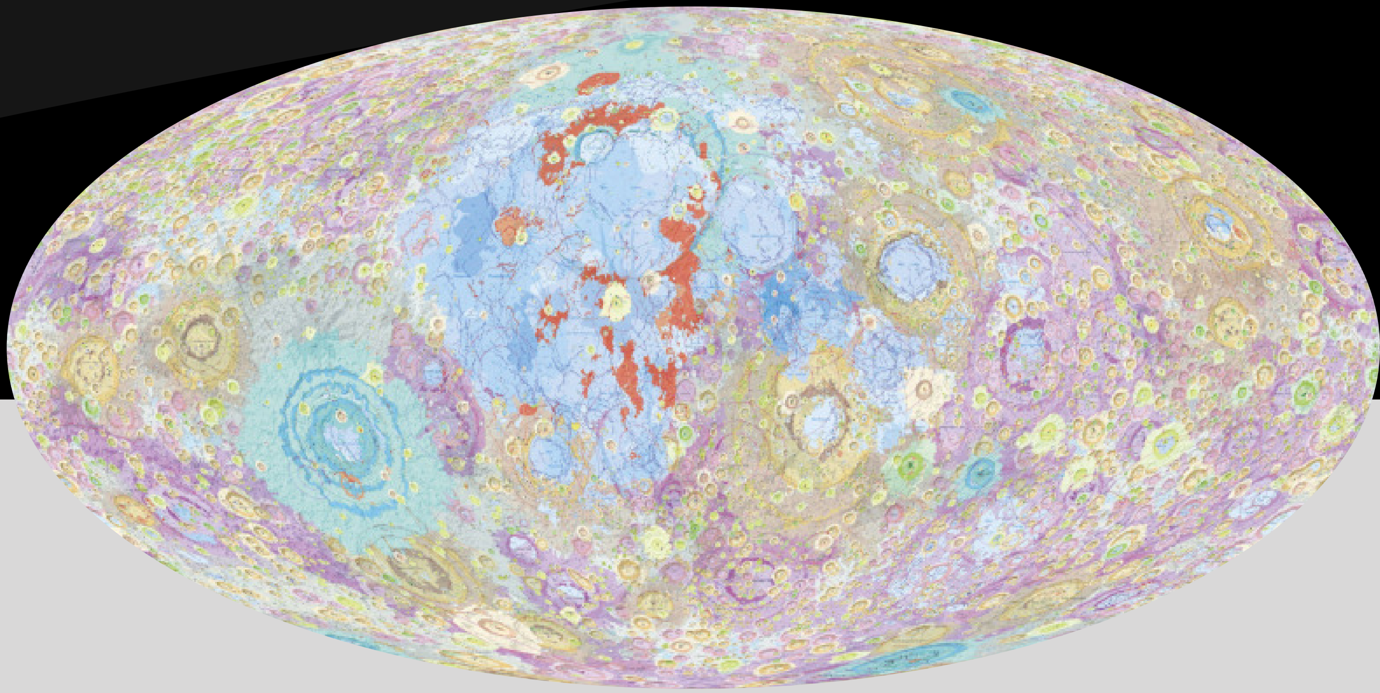
Aug. 1	14:16	I.Sh.I
	15:38	I.Tr.I
	16:25	I.Sh.E
	17:46	I.Tr.E
	20:23	II.Ec.D
	22:43	II.Ec.R
	23:10	II.Oc.D
Aug. 2	1:27	II.Oc.R
	9:47	III.Sh.I
	11:34	I.Ec.D
	11:41	III.Sh.E
	15:08	I.Oc.R
	15:40	III.Tr.I
	17:02	III.Tr.E
Aug. 3	8:45	I.Sh.I
	10:07	I.Tr.I
	10:53	I.Sh.E
	12:15	I.Tr.E
	15:28	II.Sh.I
	17:47	II.Sh.E
	18:18	II.Tr.I
	20:33	II.Tr.E
Aug. 4	6:03	I.Ec.D
	9:37	I.Oc.R
Aug. 5	3:13	I.Sh.I
	4:36	I.Tr.I
	5:22	I.Sh.E
	6:43	I.Tr.E
	9:40	II.Ec.D
	12:01	II.Ec.R
	12:28	II.Oc.D
	14:45	II.Oc.R
	23:38	III.Ec.D
Aug. 6	0:31	I.Ec.D
	1:34	III.Ec.R
	4:05	I.Oc.R
	5:32	III.Oc.D
	6:55	III.Oc.R
	21:42	I.Sh.I
	23:04	I.Tr.I
	23:50	I.Sh.E
Aug. 7	1:12	I.Tr.E
	4:46	II.Sh.I
	7:06	II.Sh.E
	7:36	II.Tr.I
	9:51	II.Tr.E
	19:00	I.Ec.D
	22:34	I.Oc.R
Aug. 8	16:10	I.Sh.I
	17:32	I.Tr.I
	18:19	I.Sh.E
	19:40	I.Tr.E
	22:58	II.Ec.D
Aug. 9	1:18	II.Ec.R
	1:46	II.Oc.D
	4:02	II.Oc.R
	13:29	I.Ec.D
	13:48	III.Sh.I
	15:40	III.Sh.E
	17:02	I.Oc.R
	19:43	III.Tr.I
	21:00	III.Tr.E
Aug. 10	10:38	I.Sh.I
	12:01	I.Tr.I
	12:47	I.Sh.E
	14:08	I.Tr.E
	18:04	II.Sh.I
	20:23	II.Sh.E
	20:54	II.Tr.I
	23:08	II.Tr.E
Aug. 11	7:57	I.Ec.D
	11:30	I.Oc.R
Aug. 12	5:07	I.Sh.I
	6:29	I.Tr.I
	7:16	I.Sh.E
	8:37	I.Tr.E
	12:15	II.Ec.D
	14:36	II.Ec.R
	15:03	II.Oc.D
	17:19	II.Oc.R
Aug. 13	2:26	I.Ec.D
	3:38	III.Ec.D
	5:33	III.Ec.R
	5:59	I.Oc.R
	9:33	III.Oc.D
	10:50	III.Oc.R
	23:35	I.Sh.I
Aug. 14	0:57	I.Tr.I
	1:44	I.Sh.E
	3:05	I.Tr.E
	7:23	II.Sh.I
	9:42	II.Sh.E
	10:12	II.Tr.I
	12:26	II.Tr.E
	20:54	I.Ec.D
Aug. 15	0:27	I.Oc.R
	18:04	I.Sh.I
	19:25	I.Tr.I
	20:12	I.Sh.E
	21:33	I.Tr.E
Aug. 16	1:33	II.Ec.D
	3:53	II.Ec.R
	4:20	II.Oc.D
	6:35	II.Oc.R
	15:23	I.Ec.D
	17:49	III.Sh.I
	18:55	I.Oc.R
	19:41	III.Sh.E
	23:42	III.Tr.I
Aug. 17	0:54	III.Tr.E
	12:32	I.Sh.I
	13:54	I.Tr.I
	14:41	I.Sh.E
	16:01	I.Tr.E
	20:41	II.Sh.I
	23:00	II.Sh.E
	23:28	II.Tr.I
Aug. 18	1:42	II.Tr.E
	9:51	I.Ec.D
	13:23	I.Oc.R
Aug. 19	7:01	I.Sh.I
	8:22	I.Tr.I
	9:09	I.Sh.E
	10:29	I.Tr.E
	14:51	II.Ec.D
	17:11	II.Ec.R
	17:36	II.Oc.D
	19:51	II.Oc.R
Aug. 20	4:20	I.Ec.D
	7:39	III.Ec.D
	7:51	I.Oc.R
	9:33	III.Ec.R
	13:29	III.Oc.D
	14:41	III.Oc.R
Aug. 21	1:29	I.Sh.I
	2:50	I.Tr.I
	3:38	I.Sh.E
	4:57	I.Tr.E
	9:59	II.Sh.I
	12:18	II.Sh.E
	12:45	II.Tr.I
	14:58	II.Tr.E
	22:48	I.Ec.D
Aug. 22	2:19	I.Oc.R
	19:57	I.Sh.I
	21:17	I.Tr.I
	22:06	I.Sh.E
	23:25	I.Tr.E
Aug. 23	4:08	II.Ec.D
	6:29	II.Ec.R
	6:52	II.Oc.D
	9:07	II.Oc.R
	17:17	I.Ec.D
	20:47	I.Oc.R
	21:50	III.Sh.I
	23:40	III.Sh.E
Aug. 24	3:36	III.Tr.I
	4:43	III.Tr.E
	14:26	I.Sh.I
	15:45	I.Tr.I
	16:35	I.Sh.E
	17:53	I.Tr.E
	23:17	II.Sh.I
Aug. 25	1:36	II.Sh.E
	2:00	II.Tr.I
	4:13	II.Tr.E
	11:45	I.Ec.D
	15:15	I.Oc.R
Aug. 26	8:54	I.Sh.I
	10:13	I.Tr.I
	11:03	I.Sh.E
	12:20	I.Tr.E
	17:26	II.Ec.D
	19:46	II.Ec.R
	20:07	II.Oc.D
	22:22	II.Oc.R
Aug. 27	6:14	I.Ec.D
	9:42	I.Oc.R
	11:41	III.Ec.D
	13:33	III.Ec.R
	17:22	III.Oc.D
	18:29	III.Oc.R
Aug. 28	3:23	I.Sh.I
	4:41	I.Tr.I
	5:32	I.Sh.E
	6:48	I.Tr.E
	12:36	II.Sh.I
	14:55	II.Sh.E
	15:15	II.Tr.I
	17:28	II.Tr.E
Aug. 29	0:42	I.Ec.D
	4:10	I.Oc.R
	21:51	I.Sh.I
	23:08	I.Tr.I
Aug. 30	0:00	I.Sh.E
	1:16	I.Tr.E
	6:44	II.Ec.D
	9:04	II.Ec.R
	9:21	II.Oc.D
	11:36	II.Oc.R
	19:11	I.Ec.D
	22:37	I.Oc.R
Aug. 31	1:50	III.Sh.I
	3:40	III.Sh.E
	7:26	III.Tr.I
	8:26	III.Tr.E
	16:20	I.Sh.I
	17:36	I.Tr.I
	18:29	I.Sh.E
	19:43	I.Tr.E

Every day, interesting events happen between Jupiter's satellites and the planet's disk or shadow. The first columns give the date and mid-time of the event, in Universal Time (which is 5 hours ahead of Eastern Standard Time). Next is the satellite involved: **I** for Io, **II** Europa, **III** Ganymede, or **IV** Callisto. Next is the type of event: **Oc** for an occultation of the satellite behind Jupiter's limb, **Ec** for an eclipse by Jupiter's shadow, **Tr** for a transit across the planet's face, or **Sh** for the satellite casting its own shadow onto Jupiter. An occultation or eclipse begins when the satellite disappears **(D)** and ends when it reappears **(R)**. A transit or shadow passage begins at ingress **(I)** and ends at egress **(E)**. Each event is gradual, taking up to several minutes. Predictions courtesy IMCCE / Paris Observatory.

Jupiter's Moons



The wavy lines represent Jupiter's four big satellites. The central vertical band is Jupiter itself. Each gray or black horizontal band is one day, from 0^h (upper edge of band) to 24^h UT (GMT). UT dates are at left. Slide a paper's edge down to your date and time, and read across to see the satellites' positions east or west of Jupiter.



Mapping the Geologic Moon

New resources can enhance your lunar understanding.

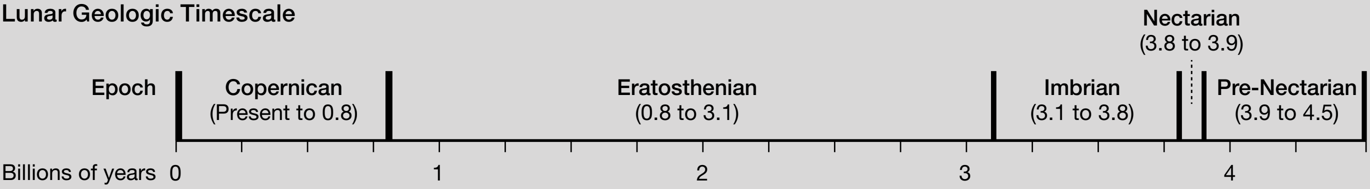
The Moon was always considered an astronomical object. After all, it's located in the sky and is best observed at night. But when, in 1962, President John F. Kennedy decided that Americans should go to the Moon by the end of the decade, it then became a geologic object. For astronauts to land on the Moon and safely return, it was necessary to know the nature and likely condition of the lunar surface. This is what geologists traditionally do — they identify the composition of the terrain as well as its origin and relation to the surrounding materials.

To prepare for the Apollo landings, the task of geological mapping was put into the hands of Eugene Shoemaker, Don Wilhelms, and their colleagues at the United States Geological Survey (USGS). They applied the fundamental terrestrial mapping concept of *stratigraphy* (how the relative position of strata relates to a terrain's age) to the Moon to determine the relative ages of surface materials. For example, the impact crater **Copernicus** provides an easy example of lunar stratigraphy — the crater and its rays sit on top of older materials. Using superposition relationships as well as other methods to determine the freshness of landforms, USGS scientists mapped the geology of the entire lunar nearside by 1971. They were mostly right in determining that maria are volcanic lava flows and bright, highly cratered terrain is much older and includes a great deal of fractured material produced during the formation of countless impact craters.

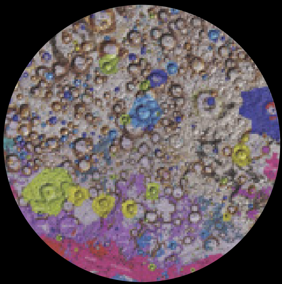
Amateur astronomers often are most interested in individual landforms, such as craters, mountains, domes, rilles, and mare ridges. And some have adopted the USGS geologic maps in order to better understand the temporal relationship of these landforms. The USGS system divides the lunar surface into five stratigraphic units, from youngest to oldest (see below). These maps have been easy to access since 2020, when the organization compiled its 1970s lunar charts into a Unified Global Geologic Map of the Moon. This map was updated in a variety of ways and, like its predecessors, has become the most widely used lunar geologic map.

Now there's another excellent resource. Beginning with the success of the Chang'e 1 spacecraft placed in orbit in 2007, the Chinese Lunar Exploration Program has grown to include probes, rovers, sample returns, and

Lunar Geologic Timescale



GEOLOGIC MAP OF THE MOON: JINZHU JI ET AL. / INSTITUTE OF GEOCHEMISTRY / CHINESE ACADEMY OF SCIENCES / CC BY 4.0; LUNAR GEOLOGIC TIMESCALE: TERRI DUBÉ / S&T



North Pole

South Pole

◀▲The USGS Unified Geologic Map of the Moon (above) and the new, larger-scale Chinese geologic map (facing page)

even plans for human exploration in the next decade. To support these missions, the Chinese Academy of Sciences has produced a large-scale map (fortunately in English) that contains even more information than the USGS map. The Chinese map is sourced from the nation's own lunar exploration program as well as from data provided by the U.S., Japan, and India lunar missions.

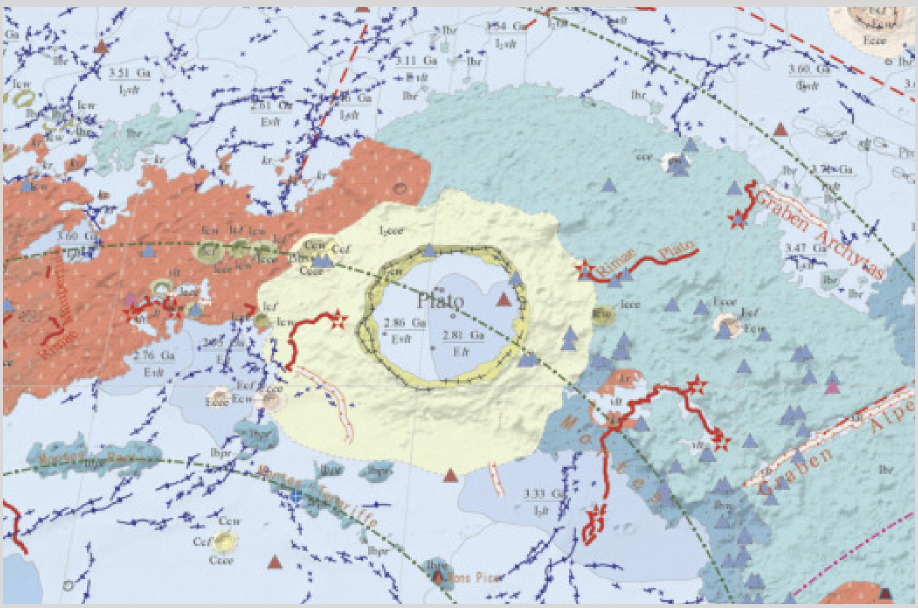
The most obvious difference between the two maps is the color scheme. The USGS map uses mostly saturated colors: Maria are shaded red, while impact craters of different ages are of various other bright colors. Young craters, such as Copernicus and others that formed in the last 800 million years, are colored yellow, and craters older than about 3.8 billion years, including **Ptolemaeus**, are tinted brown. The Chinese map color-codes geological differences with subdued pastels — all the better to read data and names on the map. Still, the Chinese map looks very much like the USGS one in that both accurately depict the same Moon. Perhaps as an homage to Earth's oceans, the lunar maria on the Chinese map are blue.

The real differences between the maps lie in the details included and how they are depicted. Both show craters and their floors, their rims and ejecta fields, mare ridges, rills, and mountains. But the Chinese map displays more of all these features in better detail. For example, impact basins are depicted with inner rims and multiple outer rings, differing from the way they've been depicted in the past. This shows our understanding of complex features is still evolving.

The Chinese map also displays the ages of maria (based on the work of Harold Hiesinger and colleagues at the University of Münster) with five shades of blue indicating different compositions of basalts, from very low to very high titanium levels. A glance at the lavas in **Mare Imbrium** reveals that the ones with flow fronts that erupted from the basin's western rim area are 2.3 billion years old with a medium titanium composition, and the surrounding lavas are about a billion years older and contain a low titanium content. I'm not aware of any other place where such information is so readily available.

The good news for observers is that both maps are freely available for download at **https://is.gd/USGS_Moon** and **https://is.gd/CN_Moon**; the files are a few hundred megabytes in size but worth the wait. Don't try looking at them on a mobile phone; they deserve large screens. And while both the USGS and Chinese maps are digital versions of traditional paper maps, the revised USGS map is included on the Lunar Reconnaissance Orbiter QuickMap site at **https://is.gd/USGSmap**. You can use this site to compare its data to gravity data, topographic data, and many other geologic data sets superposed on top of high-resolution LRO mosaics.

■ Contributing Editor **CHUCK WOOD** will be spending many evenings pouring over these new maps.



▲This detail of the Chinese map shows Plato and surrounding regions, including multiple outer basin rings as well as mare ages and compositions.

Astrophotography: Why Bother?

Understanding why we create astronomical images can be more important than knowing how.

With all the jaw-dropping images now being produced by the James Webb Space Telescope, you might wonder if amateur astrophotography still makes sense as a hobby. How can anything you create hope to compete with shots from a 10-billion-dollar telescope orbiting a million miles out in space?

In reality, photos captured by amateur and professional astronomers complement one another rather than compete. The ones acquired with large scientific instruments may look beautiful, but their core purpose is to collect astronomical data. In contrast, we amateur astrophotographers have the freedom to create whatever images we want, limited only by our skills and creativity. Plus, we're able to include foreground landscapes in our shots — something professional observatory operators can only dream about.

You may also wonder if it's worth capturing your own images given the vast numbers already created by amateur astrophotographers. The internet is positively awash in impressive shots from an uncountable number of talented and well-equipped enthusiasts. What can you possibly add to that? Why should you even try? I think these are important questions. How you answer them can help provide inspiration and give your efforts a sense of purpose.

Getting Personal

A big part of the "why" of astrophotography comes down to the special relationship you have with the pic-

GREEN SKY AT NIGHT High, thin clouds rolled in and blurred the auroral display but added an otherworldly effect for this photo of the waterfalls near Kirkjufell Mountain in Iceland. Viewing the image today brings back fond memories of the amazing locations and wonderful people the author met on his trip.

ALL IMAGES COURTESY OF THE AUTHOR

tures you take. For example, a random photo of the Andromeda Galaxy (M31) downloaded from the internet may look beautiful, but you won't have any meaningful personal connection to it — it's simply a photo of a specific object. Conversely, the images that you create are inextricably linked to the exact moment in time when you opened your camera's shutter to start the exposure. The resulting image captures not only an object but also an *experience*.

Our images have the power to remind us of events in our lives we may otherwise have forgotten. In this way, each photograph works like a little time machine, conjuring up vivid memories of the sights, sounds, and emotions we felt at a specific point in space and time. For example, I recently came across some photos I took during the 2017 total solar eclipse. Instantly, I was transported back to a dry, grassy field in Oregon. A chill came over me as I remembered the sudden change in air temperature when the world around me turned an inky blue and a soot-black hole hung in the sky where the Sun so recently shined. I remembered being surrounded by a light so metallic that I could almost taste it. There were the fleeting shadow bands on the ground and the sounds of distant birds. And with a startling suddenness — it was over. I'm so thankful I have these photos to revive my memories of that glorious, awe-inspiring day.

Experience and Reward

Of course, there's a lot more to imaging than just creating memories and experiences. Astrophotography requires incredible patience, skill, and technical know-how. Sometimes it can be a difficult and frustrating pursuit. It can also be time-consuming. Often, you'll need to spend hours traveling to a specific location, setting up your gear, and then making the exposure. Processing your pictures often takes an equivalent amount of time as you slowly tease subtle details out of the raw images. But when you step back to admire your finished work, you'll feel a great sense of pride and accomplishment. The final image is a well-deserved reward for all your effort.

I find that mixing up approaches is also a big help. Think of your camera as a passport to new perspectives and opportunities. Working as a professional photographer, editorial assignments were the most exciting part of my job. By creating an astrophotographic "self-assignment," I get a similar kind of inspiration that provides me with something to look forward to. An organized approach can help you focus your efforts and prioritize your time, which will dramatically increase your chances of success.

If you're still having trouble getting motivated, try thinking forward a few years and imagine the images you aspire to create. Maybe your self-assignment is a dramatic, wide-field shot of the Milky Way arching over a desert landscape. A closeup of solar prominences during a total eclipse. Or perhaps the northern lights dancing over a glacial lagoon. Having some kind of photographic goal can be the necessary fuel to get your creative motor running.

Even city-bound photographers can create stunning images showing the Sun, Moon, and planets. Each of these subjects presents its own unique set of challenges, but great results are certainly possible. Check out the superb solar system work produced by Damian Peach and Christopher Go if you want some inspiration — neither lives in a dark, rural countryside.

Your choice of equipment can also provide motivation. From a technological perspective, now is the best time in history to be an amateur astrophotographer. Computers and digital-imaging

▲ **ON THE CENTERLINE** Experienced eclipse chasers will counsel you to leave your camera at home and simply enjoy the spectacle visually. Obviously, the author didn't heed this advice. Here he is with some of the equipment he used in 2017, including a camera with a wide-angle lens on a tripod, plus two equatorial mounts carrying cameras mounted to a Celestron C6 telescope and a Canon 300-mm lens.

▲ **SURPLUS STUNNER** Does the world really need another photo of the Andromeda Galaxy? Probably not. But creating your own image of this classic target can be incredibly rewarding, nonetheless. This tracked portrait of M31 combines nineteen, 4-minute exposures, each captured with a Canon EF 300-mm f/4L IS USM lens at f/4 and attached to an astro-modified Canon EOS 60D DSLR camera set to ISO 1600.

CANNON BEACH MILKY WAY The author had long wanted to capture the Milky Way over the ocean. Cannon Beach, Oregon, proved to be the perfect spot to realize this "self-assignment." Although the location is fairly dark, nearby streetlights were bright enough to illuminate the large sea stack rock and the small waves rolling in.

sensors have advanced at breakneck speed over the past few decades and even mobile phones are gaining remarkable low-light capabilities. Looking ahead, the promise of computational photography and virtual reality may offer new avenues for fresh images.

Use your list of dream photos to drive your purchasing decisions when it comes to new gear. For example, a fast wide-angle lens will allow you to capture more expansive compositions of the Milky Way or an auroral display while still including an interesting foreground landscape. A sky tracker or equatorial mount enables the use of longer lenses and increased exposure times. A camera or lens upgrade can reignite your passion for astrophotography and help you approach it with a fresh perspective. In turn, this renewed interest may prompt you to consider new targets, seek out new locations, and push yourself to create better photos.

Learning for a Lifetime

Astrophotography is about much more than the gear or the results — it also provides an opportunity for lifelong learning and social interaction. There are dedicated and passionate online communities of enthusiasts from all over the world that can help guide you. Studying the work of other imagers and asking questions will expose you to new techniques and approaches to composition. Identify the elements you admire in the works of others and consider how you can incorporate them into your own images. As your skills evolve, increasingly you'll be able to add your own personal twist to the photos you create.

Sharing your shots online is a great way to connect with other astrophotographers and can even serve as a form of public outreach. When Ansel Adams created his dramatic landscape images, they demonstrated the importance of preserving and expanding the U.S. National Park System. Today, the night sky also needs protection. It's under siege from artificial lighting and increased satellite traffic. Sharing your images online will increase public awareness of the value of preserving truly dark sky locations. Conceivably, one of your photos might even inspire a stranger to think more deeply about the universe and their place within it.

As the years go by, you'll be able to look back at the portfolio of images you've created. Undoubtedly, as your skills increase, you'll see steady improvement — your most recent photos will be better than your first ones. This is one reason many astrophotographers revisit the same targets year after year.

Astrophotography requires a working knowledge of the phases of the Moon and the seasonal march of the constellations. I can guarantee that the more time you spend outside under the night sky, the more intimately you'll understand the cycles of the universe. In time, the photos you take will help you reflect on your experiences, remember them more vividly, and create a deeper connection to the natural world.

I think you'll agree that all that adds up to a pretty good "Why?"

■ TONY PUERZER is a retired professional photographer and avid amateur astrophotographer. He has been asking "Why?" ever since he was two years old.

A Deep Dive Into NGC 6822

Observe the glories of Barnard's Galaxy.

Edward Emerson Barnard is known today for a number of things. His photographic work is highly regarded, particularly his images published in 1927 in *A Photographic Atlas of Selected Regions of the Milky Way.* (For more on this fascinating story, see the article on page 28.) But he was also one of the most accomplished visual observers in history. Barnard's discovery in 1892 of Jupiter's fifth moon (which he denoted Jupiter V and is now called Amalthea) was the first addition to the gas giant's retinue since Galileo, and the last planetary satellite to be discovered visually. He identified the star in Ophiuchus that possesses the highest proper motion (about 10″ per year). At a distance just shy of 6 light-years, Barnard's Star, as we now know it, is the closest star to us in the northern celestial hemisphere and second only to the Alpha Centauri system overall.

In 1884 Barnard aimed his 5-inch refractor at an area in northeastern Sagittarius and found something that professionals continue to study to the present day. Remarkably, amateurs can explore it with a whole range of instruments, starting with 7×35 binoculars. Let's dig deeper into **NGC 6822**, or Barnard's Galaxy.

GLORIOUS GALAXY This image of NGC 6822 combines optical data from the European Southern Observatory's 2.2-meter MPG/EDO telescope at La Silla with radio data from the Atacama Millimeter/submillimeter Array (in red) located in the Atacama Desert, both in Chile. The radio observations highlight the star-forming gas clouds.

ESO / ALMA (ESO / NAOJ / NRAO) / A. SCHRUBA, VLA (NRAO) / Y. BAGETAKOS / LITTLE THINGS

A Bit of Background

During the four decades after its discovery, astronomers observed sections of Barnard's Galaxy, but it wasn't until 1922 that American astronomer Charles Dillon Perrine (then director of the Astronomical Observatory of Córdoba in Argentina) recognized the components as parts of a coherent whole. After his original observation, Barnard described it as "excessively faint" and "very diffuse and even in its light," but the object's sensitivity to atmospheric conditions and the equipment with which it was viewed became quickly apparent. Using a slightly larger telescope (a 6-inch equatorial), Barnard noted it was only "seen with difficulty." The following year, a 6-inch refractor coupled with a wide-field eyepiece boosted the object's visibility, causing its discoverer to offer, "Probably this is a variable nebula." In 1925 Hubble commented that "NGC 6822 is fairly conspicuous in a short 4-inch finder . . . but is barely discernible at the primary focus of the 100-inch."

Between 1923 and 1925, Edwin Hubble identified Cepheid variables in several Local Group galaxies, including 11 in NGC 6822. He famously determined that their distances placed them outside the bounds of the Milky Way, paving the way toward determining that the universe was expanding. Hubble also researched several features in Barnard's Galaxy, including its five brightest H II regions, the distribution of stars down to 19th magnitude, and the overall magnitude of the galaxy (published in his epochal 1925 paper "N.G.C. 6822, A Remote Stellar System").

▶ **COMING FULL CIRCLE** Three-quarters of a century after Edwin Hubble first identified H II regions in NGC 6822, the Hubble Space Telescope captured Hubble V. This giant star-forming region is about 200 light-years across.

NASA / ESA / THE HUBBLE HERITAGE TEAM / STSCI / AURA

American astronomer Paul Hodge (University of Washington) studied the galaxy several times in 1977 and noted 16 OB associations as well as open clusters, globular clusters, and H II regions. In 1991 he counted 360 stars in the galaxy brighter than 18th magnitude, including 100 between magnitudes 13.5 and 16.5. For a dedicated observer with a medium-size reflector, most of these objects are accessible.

In the microcosm of the universe that is our Local Group, we are fortunate to have a representative variety of galaxy types. Their relative proximity allows detailed study of their structure and content. NGC 6822 is classified as a barred irregular galaxy similar to the Magellanic Clouds, particularly the Small Magellanic Cloud. It's about 7,000 light-years in diameter and has a mass of around 2 billion Suns, with an absolute magnitude of –16. NGC 6822 sits 1.6 million light-years from us and is isolated from other Local Group galaxies. In a 2001 *Astronomical Journal* article, Caltech astronomer Ted Wyder noted that the galaxy is 12 to 14 billion years old and, excepting a dip 3–5 billion years ago, has been making stars steadily since its birth. He found evidence of a recent increase in the rate of star formation in the last 100–200 million years and discovered young stars in the outer halo's neutral hydrogen disk. This contrasts with other Local Group galaxies, such as the Ursa Major and Draco Dwarfs, which comprise mostly old stars, and Leo A, which consists largely of newborn stars. The microenvironments of these smaller structures, particularly their gas content and tidal interactions with other galaxies, can trigger waves of new star and cluster formation.

Myriad Observations

Lowell Observatory's Brian Skiff has spotted NGC 6822 with 7×35 binoculars, and the central bar is well within reach of 4- to 6-inch telescopes (as evidenced by Barnard's and Hubble's observing notes). As aperture increases to the 8- to 12-inch range, H II regions and some of the stellar associations become visible. Let's take a tour of some of the highlights of this remarkable object visible in larger apertures.

I first observed Barnard's Galaxy at the 1993 Texas Star Party with my 25-inch reflector. I saw it as moderately faint, diffuse, 15′ long by 4′ to 5′ wide, and with a scattering of stars across it. I also noted three bright H II regions (**H I**, **H II**, **H V**) on its northern side. In 2007 I used my 32-inch reflector from the same site and noted "many" H II regions (including **D10**, **D13**, **D16/17/18**, and **D23**), along with **PN 7** (the brightest planetary nebula in an article that Pierre Leisy and collaborators published in 2005). I needed a magnification of 361× to bag it (see the finder image on page 59 to locate the planetary and other targets). Many of the galaxy's stellar associations I've observed are within and around its H II regions. The galaxy's open structure makes them easier targets for visual observing, with the largest spanning 35″ to 100″. From the southwestern U.S. with my 32-inch I spotted several of the globulars Hubble discovered, including **H VI**, **H VII** (the largest and brightest of the lot), and **H VIII**.

In 1969 Hodge found an emission-line object in NGC 6822, now called **Ho 12**. Several years later narrowband imaging and optical spectroscopy confirmed it to be a supernova remnant. In 2004 Albert Kong (Harvard University)

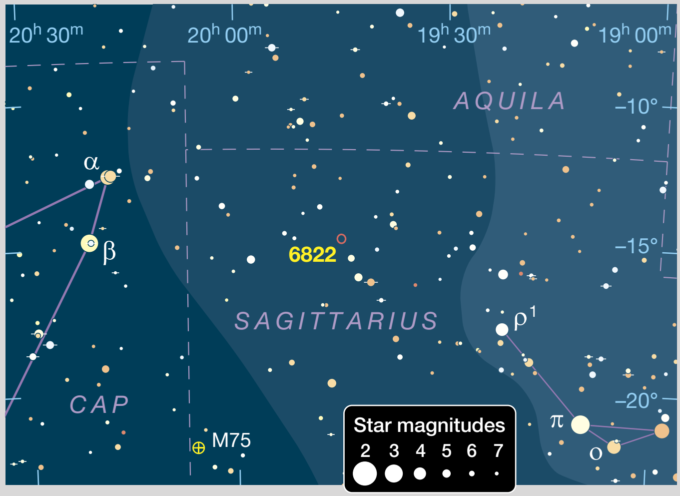
Barnard's Treats

Object	Type	Mag(v)	RA	Dec.
NGC 6822	Galaxy	8.8	19^h 45.0^m	–14° 48′
Hubble I	H II region	—	19^h 44.5^m	–14° 42′
Hubble II	H II region	—	19^h 44.5^m	–14° 45′
Hubble V	H II region	—	19^h 44.9^m	–14° 43′
D10	H II region	—	19^h 44.8^m	–14° 44′
D13	H II region	—	19^h 44.8^m	–14° 53′
D16/17/18	H II region	—	19^h 44.9^m	–14° 53′
D23	H II region	—	19^h 45.0^m	–14° 49′
PN 7	Planetary nebula	20.8	19^h 45.1^m	–14° 48′
Hubble VI	Globular cluster	16.1	19^h 44.9^m	–14° 49′
Hubble VII	Globular cluster	15.3	19^h 44.9^m	–14° 49′
Hubble VIII	Globular cluster	17.2	19^h 45.0^m	–14° 43′
Ho 12	Supernova remnant	~19–19.5	19^h 44.9^m	–14° 48′
C1	Extended star cluster	15.8	19^h 40.2^m	–15° 22′
C3	Extended star cluster	18.2	19^h 45.7^m	–14° 49′
C2	Extended star cluster	17.4	19^h 43.1^m	–14° 58′
C4	Extended star cluster	17.4	19^h 47.5^m	–14° 27′

Right ascension and declination are for equinox 2000.0.

and his colleagues studied Ho 12 at X-ray, radio, and visible wavelengths and determined it to be 10″ wide. By examining the *POSS* image, I estimated its magnitude to be 19–19.5. In August 2008 I tried to spot it with my 15-inch reflector from very dark skies in northern Minnesota but was unsuccessful. It took the increased aperture of my 32-inch from the Okie-Tex Star Party the following month to see it. I noted it to be borderline detectable with direct vision and slightly nebulous. There was a double star ½′ southwest of Ho 12 and a single star ½′ to the northeast. Kong pointed out that Ho 12 was the only known supernova remnant in the galaxy at the time.

Deep imaging in the first decade of this millennium revealed previously unknown faint structures associated with galaxies, such as tidal loops around NGC 5907 in Draco and the tail extending east-northeast of NGC 3628 in Leo. In 2006 a group led by Serge Demers (University of Montreal) found what they interpreted as a “polar ring”

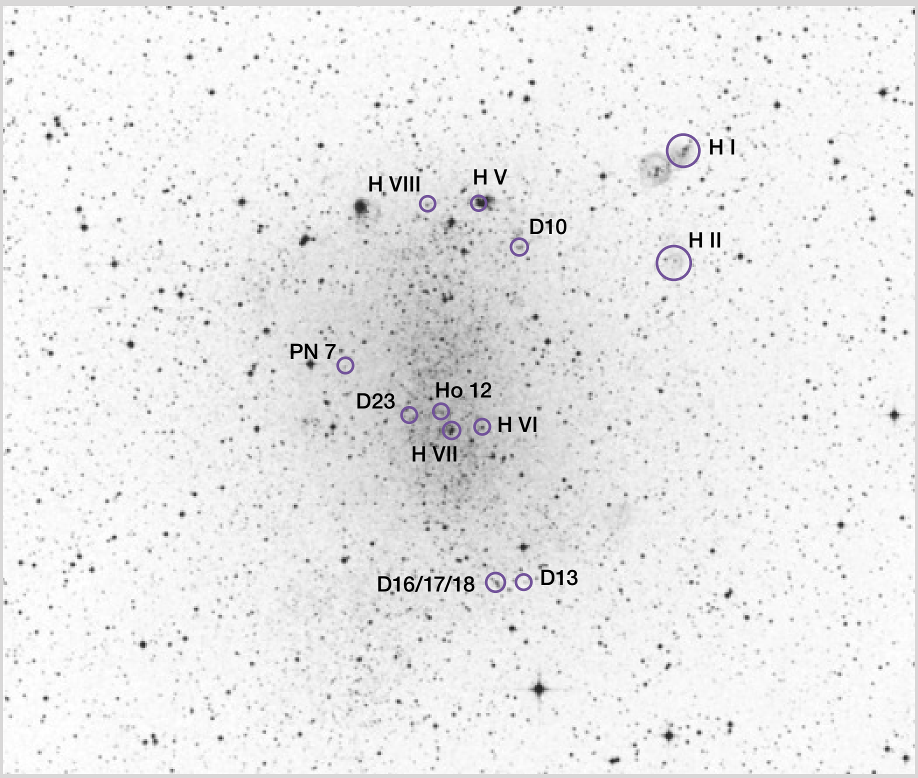


BETWEEN THE ARCHER AND THE EAGLE You'll find Barnard's glorious galaxy in northeastern Sagittarius about 3° south of the border with Aquila. The object's dimensions are 15.5′ × 13.5′.

36′ in diameter, seen at right angles to the main bar of NGC 6822. I spotted its western portion visually at Okie-Tex in 2008 using my 32-inch.

In the last few decades, surveys of the outer halos of nearby galaxies have identified a new type of star grouping called *extended star clusters*. These are larger than typical globular clusters, relatively metal-poor, and between 2 to 10 billion years old. Their properties can reveal information about the stellar structure and evolution of their parent galaxies, as in those associated with M31's stellar streams, or those in NGC 6822 aligned with its old stellar halo perpendicular to the H I disk. I used my 32-inch reflector from western Oklahoma in 2017 and 2020 to observe all four of the galaxy's known extended star clusters. At a distance of 1.6 million light-years, they're the closest ones to us. **C1** was the brightest at magnitude 16.1 and **C3** the faintest at 18.2. I saw C1, **C2**, and **C4** as nonstellar and C3 as stellar (though for C4 I was observing in poor conditions through wildfire smoke).

It has taken more than a century to unlock these secrets from the galaxy Barnard discovered. NGC 6822's position within our Local Group allowed it to avoid interaction with the three large spirals, so it's relatively pristine and unperturbed in its development, something astronomers value. Due to its open structure and lack of thick layers of dust (such as those found in M33 and M31) we can — as with an X-ray of a broken arm — see through its body to observe its many parts. Next time you're hunting between the Eagle and the Archer, take a look at one of the most fascinating galaxies in the sky.



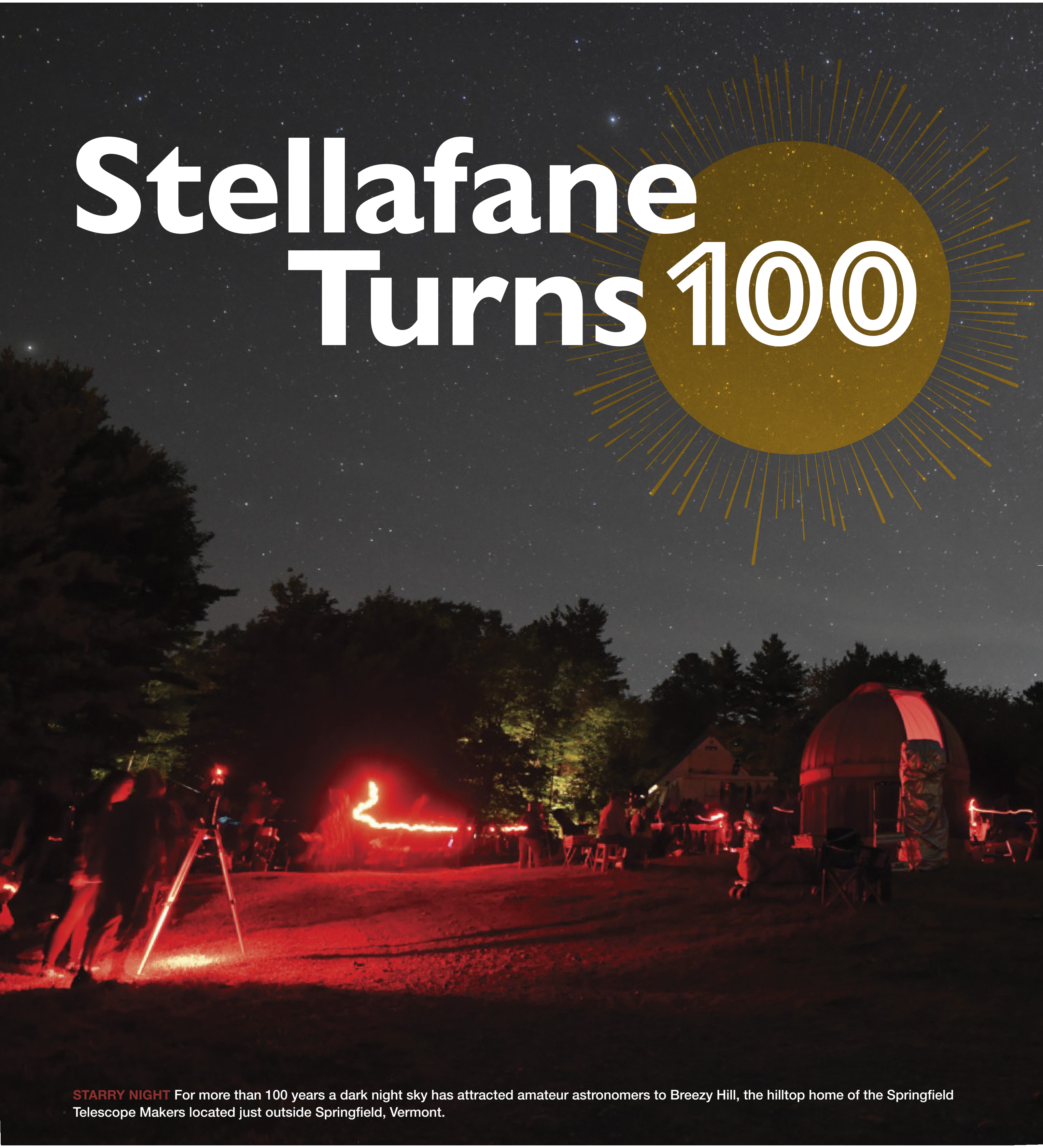
POSS-II / STSCI / CALTECH / PALOMAR OBSERVATORY

BRIMMING WITH TARGETS Barnard's Galaxy, also known as Caldwell 57, has a plethora of targets that you can snag with your telescope. You'll need aperture, but these are all within reach of amateur equipment. The extended star clusters are outside the field. Image size is 24′ × 20′.

DAVE TOSTESON gets no deeper joy from observing than to understand and share our visible universe.

FURTHER READING: For a concise history of the discovery and subsequent early observations of NGC 6822, see Richard Jakiel's fine article at **https://is.gd/NGC6822_Jakiel**.

Stellafane Turns 100



STARRY NIGHT For more than 100 years a dark night sky has attracted amateur astronomers to Breezy Hill, the hilltop home of the Springfield Telescope Makers located just outside Springfield, Vermont.

The group of Vermont amateurs that became the focal point of the telescope-making movement in North America is celebrating a milestone anniversary.

Any anniversary involving a zero is noteworthy, but when it involves two zeros it's time for a special celebration. And that's what Vermont's Springfield Telescope Makers (STMs) is planning for its Stellafane Convention this coming August. These annual events held atop Breezy Hill on the outskirts of Springfield, Vermont, have grown to become one of the oldest and most widely known gatherings of amateur astronomers in the world. It's something that the handful of telescope makers could hardly have imagined when they officially formed their club a century ago on the evening of December 7, 1923.

The club's roots, however, go back several years to the summer of 1920, when Springfield native Russell W. Porter offered to teach a group of 15 men and one woman how to grind and polish telescope mirrors. It was something that he'd taught himself with the help of scant published materials during the previous decade. All but one of the men finished their mir-

▲ **FIRST CLASS** The original group of telescope makers organized by Russell W. Porter (holding mirror left of center) gathered for a group photo in August 1920. Most of them continued on to formally establish the Springfield Telescope Makers in December 1923.

ALL BLACK AND WHITE IMAGES: THE STELLAFANE ARCHIVE; ALL COLOR IMAGES: COURTESY OF THE AUTHOR; STARBURST: WHOLE HEARTED / SHUTTERSTOCK.COM; PICTURE FRAME: VECTORTATU / SHUTTERSTOCK.COM

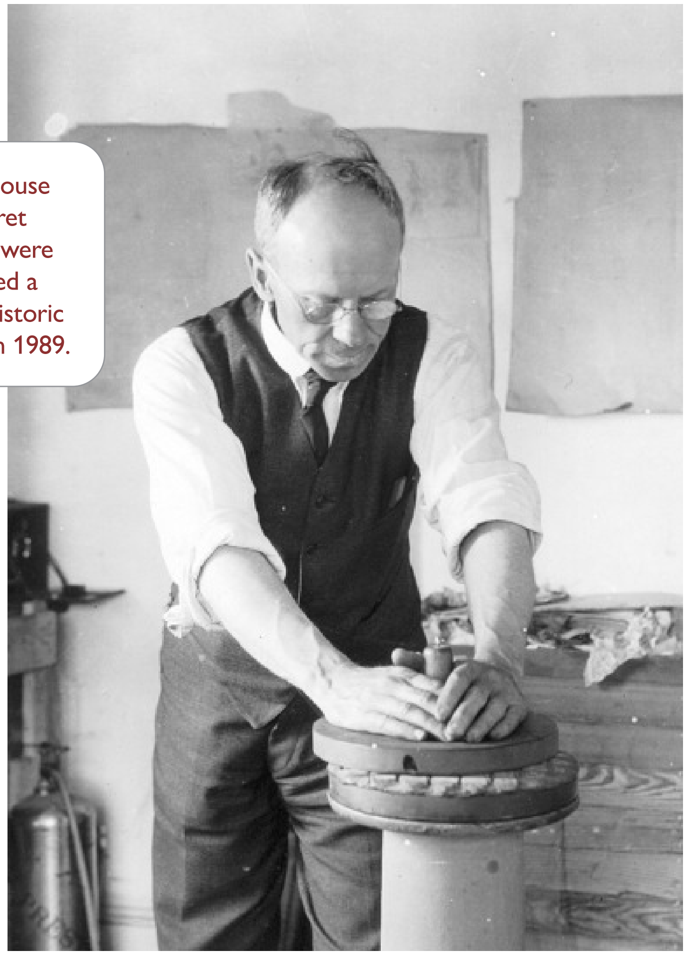
rors and most went on to complete working telescopes. During the years that followed they got together to observe at various homes and while on overnight camping outings.

Porter had inherited a small plot of land atop Breezy Hill, where his family had a rustic shack dating back to the turn of the century. By the fall of 1923 he offered to lease the land to his group of telescope enthusiasts, and they soon began construction of a clubhouse on the site, with the intent of making it their permanent location for observing parties. On the December evening of the club's first official meeting, they elected Porter president and set a goal of quickly finishing the clubhouse. By the end of January the structure was ready for use, and the club accepted Porter's suggestion that it be named *Stella Fane*, meaning shrine to the stars. It soon morphed into the familiar Stellafane.

The clubhouse and turret telescope were designated a National Historic Landmark in 1989.

Russell W. Porter

By the time Porter organized his telescope makers he was already middle-aged and had packed more than a lifetime of adventure into his 51 years. While in his 20s and studying architecture in Boston in 1892, he attended a lecture by arctic explorer Robert E. Peary and immediately became consumed with a case of "arctic fever." During the next two decades Porter participated in nearly a dozen northern expeditions, often signing on with major assignments as an artist and



▶ **PUSHING GLASS** Porter, seen here polishing a 10-inch mirror in the early 1920s, taught himself the art of telescope making from the little published information available during the previous decade.

Clubhouse Evolution

▲ **ASTRO SHANTY** Russell Porter owned this crude shack atop Breezy Hill on the outskirts of Springfield, Vermont. He later leased it and eventually sold the land it was on to the STMs for $1, with the intent for it to become a permanent home for the club.

▲ **EMERGING SHRINE** In addition to electing Porter as president on the evening of December 7, 1923, when the STMs formally organized as a club, the membership set the completion of the clubhouse (seen here during the fall of 1923) as a priority.

surveyor. Several of these expeditions had a goal of making an assault on the North Pole, but the farthest Porter reached was a little above the 82nd parallel in 1901. His most harrowing experience, however, came two years later. While participating on another expedition, his ship was trapped and crushed by winter ice and ultimately sank. The team was stranded for two years before a rescue ship finally reached them.

With his arctic years behind him, Porter became increasingly interested in astronomy and telescopes, partly because of the astronomical observations he undertook while acting as a surveyor on the expeditions. Upon his return to more temperate climates, his interest was also aided by his long-time friend from Springfield (and future governor of Vermont) James Hartness, who was an avid amateur astronomer. By the time of Porter's return to Springfield in 1919, he had taught himself how to make telescope mirrors and had written several articles about his experiences in the well-known publication *Popular Astronomy*.


EIGHTY-FIRST YEAR

SCIENTIFIC AMERICAN

THE MONTHLY JOURNAL OF PRACTICAL INFORMATION

NEW YORK, NOVEMBER, 1925

"The Heavens Declare the Glory of God"

How a Group of Enthusiasts Learned to Make Telescopes and Became Amateur Astronomers

By Albert G. Ingalls

"WHY not make your own telescope?" said Mr. R. W. Porter, the telescope maker, as the waiter in a famous Broadway chop house started for the kitchen with our order. "Astronomy would mean a lot more to you if you did."

We had met to talk about Porter's hobby, astronomy. I had already heard quite a lot about this versatile man whose whole life had centered about the study of the stars. In his earlier years he had spent a dozen winters in the Arctic as astronomer, topographer and artist. Three years he had been with Peary, three more with Fiala in Franz Josef Land, and two years with Cook, who Porter says certainly did not climb Mt. McKinley. Other seasons he spent in northwestern Canada and in unknown Labrador. During all these years in the Far North where the Arctic stars fairly snap in the cold, clear air, he was studying astronomy.

Now he had settled down in the picturesque manufacturing village of Springfield, Vermont, tucked away in a deep valley in the foothills of the Green Mountains, where, as everyone in the mechanical industry knows, a famous type of flat turret lathe is made. Here he had fired a score of men with his own keen enthusiasm for the stars and had organized them into a group which is perhaps unique—machinists by day, amateur astronomers by night.

"You'd have no trouble in making a good telescope," he assured me.

"I could make the mounting all right," I replied, "but when it came to making the optical parts I'd be out of it. Only a handful of men in the world are skilled enough to do that fine work."

"You come up to Springfield, where I live," he laughed, "and I'll show you a good many homemade telescopes, made in spare time by men who knew nothing about it when they began. They'll tell you how any amateur—even an editor—can make his own telescope for less than fifty dollars, providing he's reasonably handy and will take pains. And it will be a real telescope, fit for serious work, not just a toy or a makeshift."

The "Poor Man's Telescope"

He went on to tell me how in the Vermont village a group of men, most of them mechanics in the local machine shops, had banded together to study the stars; how each one had made and mounted his concave mirror; how they had later pooled their efforts and built a sort of combined clubhouse, lodge and observatory on the top of a mountain near their homes. Here they gathered when the week's work was done, to study the stars. "The Telescope Makers of Springfield," they call their club, and none may join who has not made his own telescope.

When summer rolled around, I went to Springfield, as Porter had suggested, and there the amateur astronomers told me how they had learned their new avocation.

There are two common types of telescopes, the refractor and the reflector. The refractor is the ordinary type that everyone knows. It is like a big spyglass; you look through it, the light actually passing through its lenses. For serious amateur work such a telescope, having an objective lens four inches in diameter, is very valuable, but it costs several hundred dollars to buy, while the ordinary amateur cannot hope to make it himself.

But the reflector works on a different principle. It is a shorter, thicker instrument having a large, round, concave mirror in its lower end. The light coming from a star strikes this concave mirror and is reflected upward in a converging cone. Near the upper end of the big tube, which is open at the top, a small diagonal mirror or sometimes a three-sided prism of glass is mounted in such a position that the cone of light reflected by the large mirror is intercepted and is turned at right angles toward the eyepiece in the side of the telescope. Owing to the fact that the light does not pass through the glass as in the other type of telescope, the mirror does not have to be made of optical glass—simply ordinary thick plate glass; and since the mounting of

ON THE SPRUCE-CLAD SUMMIT OF BREEZY MOUNTAIN THE VERMONT ASTRONOMERS HAVE BUILT THEIR STELLAR FANE. A SEVENTY-FIVE FOOT SOLAR TELESCOPE PROJECTS THE SUN'S IMAGE ON A SCREEN INDOORS

In this type of telescope, no tube is required. The light from the sun is reflected by the siderostat, flat, plane mirror B, to an equally large concave, paraboloidal mirror mounted on a stone pier at A. Thence the light converges through a circular opening just above the first mirror, and focuses on the screen, C, where the amateurs study the sun's image

◀ **POSITIVE INK** To learn more about telescope making, *Scientific American* editor Albert G. Ingalls visited the STMs in the summer of 1925 and followed up with a cover story in the magazine's November issue. It and subsequent articles soon turned the Vermont club into the de facto center of the telescope-making hobby in North America.

▲ **UNIQUE REFLECTOR** The clubhouse had reached maturity by 1930 when the famed Porter Turret telescope was being built.

▲ **PINK PILGRIMAGE** The present-day clubhouse remains largely unchanged from the 1920s. It's seen here in 2017 when club members gathered for a pre-convention meeting.

Birth of the Stellafane Convention

As word of the club's telescope-making activities spread it attracted the attention of several magazine editors, including Albert G. Ingalls of *Scientific American,* who was having trouble grinding his own telescope mirror at the time. Ingalls traveled from New York to meet with the STMs at Stellafane in July 1925, and the visit resulted in a cover story for the magazine the following November. This and subsequent articles, some written by Porter, quickly gave birth to the amateur telescope making (ATM) movement in North America and put the STMs and Stellafane at the epicenter of the rapidly growing hobby.

Within months Ingalls was in contact with an increasing number of amateur telescope makers, and the STMs thought it would be great to invite as many as possible to gather at

▲ **TRADITION BEGINS** In July 1926, participants at the first official Stellafane Convention had plenty of room to assemble at the steps of the clubhouse for their group photo. Porter is at lower right; Ingalls is seated behind the young man at left with hands on knees.

▶ **GROWING GROUP** Only a year later, the 1927 convention participants had to move to the sloping ground in front of the clubhouse terrace to find enough space for their group shot.

▶▶ **HILLTOP CROWD** When Stellafane held its 50th convention in 1985, there was barely enough room on the western edge of the cleared hilltop for a group photo.

Notable People at Stellafane

▲ **MOON WALKER** Stellafane has hosted its share of famous people, but none more widely known than the late Apollo 12 astronaut Alan Bean, who was the fourth person to set foot on the Moon. He's seen here in 2009 enjoying a conversation with a convention regular at a dinner held in his honor.

▲ **TRUE GRIT** Among the fraternity of amateur telescope makers, few are better known than the late John Dobson (the namesake of the Dobsonian telescope design), who was a frequent convention attendee until his death in 2014. He's pictured here putting some muscle into a rough-grinding demonstration for a 27-inch mirror during the 1996 convention.

▲ **TEAM COVERAGE** Members of the *Sky & Telescope* editorial staff were regular attendees after the annual conventions resumed in 1954. This group shot from 1992 includes then Editor in Chief Leif Robinson (wearing sunglasses second from right) and future Editor in Chief Rick Tresch Fienberg (back row center). The author appears at lower right.

Stellafane. About 20 did just that on the July 4th weekend in 1926. Everyone had such an enjoyable time that it was decided to hold the event annually. Numbers grew rapidly, with 59 participants registering for the 1927 convention; in 1929 more than 110 signed up.

1929 was also the year that Porter's skills as an architect and telescope maker earned him a spot on the team that George Ellery Hale was assembling in California to build a 200-inch telescope — work that would be yet another major chapter in Porter's life. Although this made the STMs' founding father less involved with club activities, the Stellafane conventions continued yearly until World War II intervened. But the interruption did not stop some of the telescope makers from contributing to the war effort by making roof prisms for the military.

In the early 1950s there was growing interest among the amateur community in renewing the Stellafane conventions. With major help from the Amateur Telescope Makers of Boston, the convention was resurrected in the summer of 1954, and the STMs has continued them annually ever since, with the exception of 2020 when the COVID pandemic cancelled virtually all public gatherings.

Stellafane conventions have always served as a snapshot of emerging trends in the world of amateur telescope making. A few of the highlights of past conventions and the people who have made the pilgrimage to the top of Breezy Hill are shown in the accompanying photos. But what's more difficult to illustrate is the camaraderie and friendship that permeates every convention. The upcoming gathering, which runs from August 17 to 20, will be no exception. The STMs invites everyone to join the club in kicking off its 100th anniversary celebrations. Information is available at **stellafane.org**.

■ With the exception of 2008, **DENNIS DI CICCO** has attended every Stellafane Convention since 1967.

▶ **ASTROSCAN BETA** *Top:* Many of the telescopes displayed at Stellafane conventions have given attendees a glimpse of the future. In 1967, Californian Norman James fascinated everyone with his prototype 10-inch reflector housed in a fiberglass sphere floating in a water-filled base. In subsequent years he returned with increasingly refined versions that ultimately influenced the design of the famous Astroscan telescope introduced by Edmund Scientific in 1976 as well as an array of professional 1.5-meter telescopes built by avant-garde astronomer Antoine Labeyrie in the French Alps in the early 1980s.

▶ **EARLY GO TO SCOPE** *Middle:* In what was a first for amateur telescopes, Canadian Jean Vallieres brought his computer-controlled telescope to the 1976 convention. It could automatically point with ½° accuracy to as many as 256 celestial objects stored in internal memory.

▶ **FAUX DOB** *Bottom:* Seeds of the Dobsonian revolution were sown at the 1977 convention when this altazimuth-mounted 16-inch reflector was on display. Built with optics donated to the Amateur Telescope Makers of Boston, it was inspired by the telescopes John Dobson had brought to the Riverside Telescope Makers Conference in California the year before. After seeing the scope at Stellafane, Richard Berry, editor of *Telescope Making Magazine*, built a version of his own and began championing the design. The rest is, as they say, history.

The RST-135 Weightless Mount

This strain-wave telescope mount is great for both casual observing and serious astrophotography.

Rainbow Astro RST-135

U.S. Price: $3,895 (head only)
rainbowastro.com

What We Like

Small and portable

Accurate Go To

Works in equatorial or alt-az mode

What We Don't Like

Large periodic error

Lacks periodic-error correction

Hand controller steep learning curve

THE ADAGE THAT "bigger is better" is not aging well, at least not when it comes to astrophotography. The current trend is toward portable imaging with smaller telescopes, which means smaller mounts are needed to put them on. And along with this new emphasis on portability, a new technology has arrived — the "harmonic" mount. Such units use "strain-wave" gearing technology, originally developed for industrial robotics, to create compact but very strong mounts capable of handling a hefty telescope without the need for heavy counterweights to balance the load. (See Dennis di Cicco's Sharpstar Mark III review in the January issue for one example.)

My first encounter with strain-wave gearing was at the Northeast Astronomy Forum (NEAF) in 2018, where Korean manufacturer Rainbow Astro exhibited some of the earliest mounts featuring this technology. My first impression of this tiny beast was "that's inconceivable." I had a hard time believing such a tiny mount could produce good results with much more than telephoto lenses.

Skipping forward a few years, I found myself looking more carefully at these while attending the Advanced Imaging Conference in San Jose in the late spring of 2022. There, *S&T* arranged for me to borrow a Rainbow Astro RST-135 mount from Tolga Astro (**tolgaastro.com**) to see how well it performs.

◀ The Rainbow Astro RST-135 mount uses high-torque, strain-wave gearing to achieve an impressive load capacity of 13.5 kilograms (30 pounds) without needing counterweights. The saddle plate shown isn't included with purchase.

Size Can Be Deceptive

The RST-135 is the smallest model of dual-axis, strain-wave mounts offered by Rainbow Astro (a division of Rainbow Robotics). The dual-axis drive head is roughly 14½ × 13 × 19½ centimeters (5½ × 5 × 8 inches) and weighs just 3.3 kilograms (7 pounds). Despite this compact size, it's rated to carry a payload of 13½ kg.

The mount arrived with its Hubo-i SE hand controller, a QHY PoleMaster ring adapter to aid polar alignment, a USB 2.0 cable, but no power supply or AC adapter. The company recommends a power supply that provides 12 to 16 volts DC at 3 amps and accepts a center-positive, 2.1-mm jack. While tracking the mount draws only about 0.2 amps, and during slews I saw between 1 and 2 amps of power draw. The head fits into a small, padded bag, and with the exception of the tripod, the whole kit easily fits in a backpack or airline carry-on.

▶ On the south end of the mount are large knobs that allow precise adjustments during polar alignment. An assortment of bolt holes permits the user to connect a wide variety of telescope mounting plates or dovetail clamps. The white telescope illustration indicates the direction that your optical tube assembly should be facing when installed on the mount.

ALL IMAGES COURTESY OF THE AUTHOR

▲ *Clockwise from top left:* The mount includes a soft case, the RST-135 drive head, the Hubo-i SE hand controller, a hex wrench, the hand controller cable, tripod and PoleMaster adapters, a 2-meter USB 2.0 cable, and two power cables.

An optional counterweight kit is available for $160 that increases the mount's payload capacity to 18 kg, though I didn't test it with this option. A bit more surprising with the RST-135 is that a dovetail saddle to attach your optical tube assembly is considered an optional accessory. This is a modular mount, so you'll need to have or purchase a dovetail clamp or other means of connecting your OTA. The head has many threaded holes to accommodate a wide variety of options, and Tolga Astro offers several for purchase on its website. Fortunately, I had a dovetail adapter that fit one of its many bolt patterns. I tested the RST-135 with several telescopes, including an Astro-Physics 92-mm Stowaway, a Sky-Watcher Esprit 100 refractor, and a Sky-Watcher 180-mm Maksutov-Cassegrain.

Users also need to supply their own tripod or pier for the RST-135. A tripod with a wide stance is recommended, as a telescope with an unbalanced load may topple over if the tripod it's attached to doesn't have a large footprint to accommodate the weight shifting from one side to another while slewing to objects around the sky. I was initially worried about this on my first outing but soon became more confident, as none of my loads extended far enough from the tripod's center of gravity to cause any problems.

The appearance of the RST-135 is sleek. It's well-machined, with an anodized finish and solid workmanship all around. There's no slop or loose motion in either axis. In fact, because of the strain-wave gearing (driven by Swiss-made Maxon DC servo motors), it's hard to move either axis when the mount isn't powered up. There are no clutches or release mechanisms that permit the axes to swing freely in order to balance the load. A steady pressure can move both axes slowly. When parked with the scope positioned horizontally, the load will stay in position when the mount is powered down. However, if the scope is positioned far to one side of the RA axis or well out of balance in the event of a power loss, the scope will slowly drive down and eventually collide with the tripod. It's quite a different story when the power is on — I couldn't move the scope by hand at all.

The mechanical adjustments on the mount were smooth and performed well, even with all my gear mounted up. The mount arrives with its RA axis aimed at 90°, so you'll need to move it closer to your latitude setting. This is done by loosening a bolt recessed within a slot on the side of the mount, below the altitude locking knob. Move the axis until it's close to your latitude, tighten the bolt down, then use the large knob on the south side of the mount to make fine

◀ To make large adjustments when aiming the RA axis, use the included hex wrench to loosen the bolt located in the slot below the large, winged altitude locking knob on the west side of the mount base.

▶ The north-facing end of the RA axis contains a guider port, power switch, and three indicator lights. A USB 2.0 port on the right side connects the mount to your computer, while the lower port accepts the Hubo-i SE hand controller.

adjustments during polar alignment. This knob will move the mount up and down by up to 20°. You can also move the axis all the way down and operate the RST-135 in alt-azimuth mode.

Hand Paddle Control

Using the included Hubo-i SE hand controller, the mount can be used for visual observing and short-exposure astrophotography. However, I didn't find the controller very intuitive, and it took a good deal of getting used to. It was impossible to use without consulting the user's manual and searching some online forums for hints and tips. The controller's menus list substantial capabilities beyond those that this mount is capable of performing. That's because the Hubo-i SE is a generic hand controller offered with a wide range of telescope mounts. Searching through the menus you'll find periodic error correction, balance assistance, and reticle illumination — none of which the RST-135 supports. The RST-135 has built-in Wi-Fi, so you can also connect and control the mount using smart-device apps with telescope control, including *SkySafari*.

On my first night out I made the classic mistake of trying to figure out the hand paddle without so much as a glance at the user manual and ended up frustrated. After spending some time with the documentation, I learned that I need to press the ESC key after homing the mount (sending it to a known reference position) before anything else works. To activate the menu, you press and hold the ENT key for a couple of seconds, not the key labeled MENU. The ALIGN button on the keypad is not for your star alignment but instead for activating the polar alignment routine. The ESC goes back one level, rather than the button labled PREV.

Once you get over the learning curve, the hand controller does everything you need for visual observing, with several particularly nice features. For instance, it homes the mount simply by pressing and holding ILL or the Zero key for a couple of seconds. There's also an integrated GPS to set the time and location.

The hand paddle includes a polar-alignment assist routine that is useful. However, the easiest and most accurate way to polar align is with QHYCCD's PoleMaster polar-alignment camera and software (see *S&T:* July 2018, p. 72). The mount head has a raised circular feature on the front of the mount that the included PoleMaster adapter attaches to. The mount's altitude and azimuth adjustment knobs permit very precise adjustments and produced excellent polar alignment in a minute or two with the aid of the PoleMaster.

◀ The Hubo-i SE hand controller includes a four-line display and lots of buttons, though users are strongly cautioned to read the manual before taking the mount out under the stars.

I was most impressed with the accuracy of the 6 STAR alignment option in the hand controller. Once polar aligned, you use this feature to sync the mount on up to six stars in order to improve its internal pointing model. I found the accuracy to be rather good after syncing on only one star after the mount was properly leveled and polar aligned. However, adding 5 more stars widely spaced across the sky resulted in pointing accuracy unparalleled in my experience for a mount that isn't connected to an external computer running a premium planetarium program. Even at high magnifications, objects were dead center in the eyepiece all over the sky after each slew.

Another nice option is the polar-error compensation feature called Drift Correct. It uses the six-star pointing model to drive the mount in both axes in order to compensate for any remaining polar-alignment error to keep objects centered. This feature is activated by selecting Drift Correct, On in the hand controller main menu.

The controller also includes the option to save the pointing model for use on multiple nights. This means that so long as you haven't moved the setup, you can just re-home the mount on startup without having the mount create a new pointing model.

▲ *Left:* Users with a QHYCCD PoleMaster or similar polar-alignment aid can connect the included adapter to the raised disk on the north-facing end of the polar axis. *Right:* After securing the adapter, you can then quickly connect or remove the PoleMaster camera after use.

Deep-Sky Imaging

Using the mount with the hand controller was sufficient for lunar and planetary photography. For longer exposures, however, I found it more intuitive to control the mount, camera, autoguider, and focuser with *TheSky Imaging Edition* using a native plug-in provided by RTI-Zone (**rti-zone.org**). The RST-135 is ASCOM-compatible and will connect to most every PC control program.

▶ The RST-135 can carry a heavy load without any problems at all. But be aware that this compact mount has several large, easy-to-grip knobs that can easily snag any slack wires or cables dangling from astro-imaging gear.

My first substantial test use of the mount was at the Grand Canyon Star Party last summer, where I used it for live-stacking deep-sky targets during the outreach portion of the evening. This was when I first encountered the biggest and only real drawback to this new drive technology. Despite excellent polar alignment, roughly half of the 10-second exposures I recorded showed elongated stars. The reason is the fairly high periodic-error value of about 30″ over 430 seconds. For very short exposures this was okay, but if you want to take long exposures of deep-sky targets, you simply must autoguide — and guide fairly aggressively.

After some experimentation, I had no trouble at all autoguiding the RST-135. There appears to be no substantial backlash in either axis, so you should be careful that you do not get caught "chasing the seeing" with your autoguiding settings.

One note about imaging with the RST-135 is the mount will stop tracking when it reaches the meridian, but you can change where this stopping point is in the hand controller's system menu. Of course, this should be done with care because the drives are quite powerful and can potentially shear cables or damage your equipment in the event of a collision with the tripod.

A challenge I had with such a compact mount was cable management. The large, easy-to-use knobs almost magically seemed to attract loose cables. One night, the autoguider cable got ripped right out of its connector. The cable was ruined, but fortunately nothing else was damaged.

And the Verdict Is . . .

The RST-135 is a fine choice as a versatile, portable mount. It has an impressive load capacity for such a compact unit. Its ability to be used in either alt-azimuth or equatorial modes makes it just as comfortable for casual observing and outreach as it is for high-end astrophotography. And the integrated pointing model and tracking adjustments are both hands-down winners in my book.

■ Contributing Editor **RICHARD WRIGHT** is always looking for small portable imaging setups as an excuse to travel to dark skies.

The RST-135 had no problem autoguiding the 92-mm Astro-Physics Stowaway refractor used to create this image of NGC 2359, Thor's Helmet, in Canis Major. The image consists of 141 individual, 4-minute exposures recorded with a Player One Astronomy Poseidon-M camera fitted with color and narrowband filters and the telescope operating at f/7.

Toward Lunar Observatories

BACK TO THE MOON: *The Next Giant Leap for Humankind*

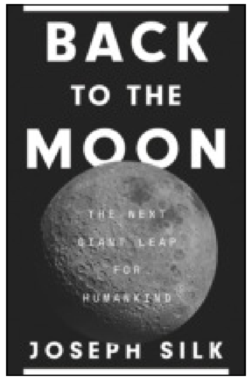
Joseph Silk
Princeton University Press, 2022
304 pages, ISBN 9780691215235
US$29.95, hardcover

BACK TO THE MOON paints an exciting vision of planned human activity on and around the Moon in coming years and decades: crewed bases at craters in the south polar region and larger settlements in lava tubes; an orbiting spaceport, together with communications and data-relay satellites; robot-assisted mining of lunar resources; even tourist resorts. Importantly for author Joseph Silk (and *S&T* readers), this expansive view includes giant observatories.

Some distinguished scientific experts urge that further exploration of the Moon and beyond be conducted robotically, not by astronauts (*S&T:* Dec. 2022, p. 70). But Silk, a renowned astrophysicist at Johns Hopkins, argues that the train has left the station — whether we like it or not, humans are returning to the Moon. NASA's Artemis program intends to send people there as early as next year, and the Chinese space agency is not far behind. Industry in many countries is studying how to profit from lunar materials. And a wide variety of orbiters, landers, and supporting facilities are planned, in development, or already on the way to Luna.

> "Who can possibly predict what marvels may await us? How can our space agencies possibly resist such a challenge?"

Silk thinks astronomers can benefit from these endeavors to develop lunar observatories. Such telescopes could boast a sensitivity 1,000 times greater than that of the James Webb Space Telescope (JWST). That unprecedented light-gathering power would greatly increase our ability to investigate the origins and ubiquity of life, for example. Huge lunar infrared and optical telescopes might detect biosignatures in exoplanets' atmospheres and starlight reflected off their surfaces.



Other kinds of observations would also benefit from the lunar environment. Low-frequency radio emissions from an exoplanet might indicate the presence of a global magnetic field, which might help protect extrasolar life (if it exists) from stellar flares, just as Earth's magnetic field safeguards us. The lunar farside is ideal for such observations.

Meanwhile, a lunar gravitational-wave observatory could measure such waves from merging intermediate-mass black holes. Such an observatory could fill the gap between Earth-based facilities such as LIGO (which detects collisions of stellar-mass black holes) and the planned Laser Interferometer Space Antenna, or LISA (which will focus on mergers of supermassive black holes). Astronomers need those data to complete our census of black holes (*S&T:* Nov. 2022, p. 16).

Astronomers using JWST have already observed galaxies from just after the cosmic "dark ages" ended, a few hundred million years after the Big Bang. Silk suggests that an infrared telescope on the Moon might see individual, very massive *stars* from the same era. Such a lunar scope might have a 400-meter (1,300-foot) aperture, an order of magnitude larger than, say, the 39-meter primary mirror of the European Extremely Large Telescope (ELT) now under construction in Chile.

For his part, Silk particularly hopes that we'll use lunar radio telescopes to detect and measure the small hydrogen clouds that are thought to represent an early stage in the development of structure in the infant universe. Neutral hydrogen emits in the radio, at a wavelength of 21 cm. The expansion of the universe has since shifted early clouds' emission to longer wavelengths (lower frequencies), which astrophysicists can best study from the lunar farside.

As Silk writes, "Only radio searches can seek the highly redshifted low-frequency radio waves that reveal the secrets of the primeval hydrogen clouds that were the building blocks of galaxies." Ideally, he would have us observe the clouds with a 100-km-square array of millions of simple dipole antennas, installed by human-supervised robots and serviced by data-relay satellites.

Silk sums up his thinking by noting that "megatelescopes" on the Moon would allow a leap forward in aperture size similar to what was made between Galileo's first telescope and JWST. "Who can possibly predict what marvels may await us?" he enthuses. "How can our space agencies possibly resist such a challenge?"

■ **STEVE MARAN** is the former press officer of the American Astronomical Society, which publishes *Sky & Telescope*.

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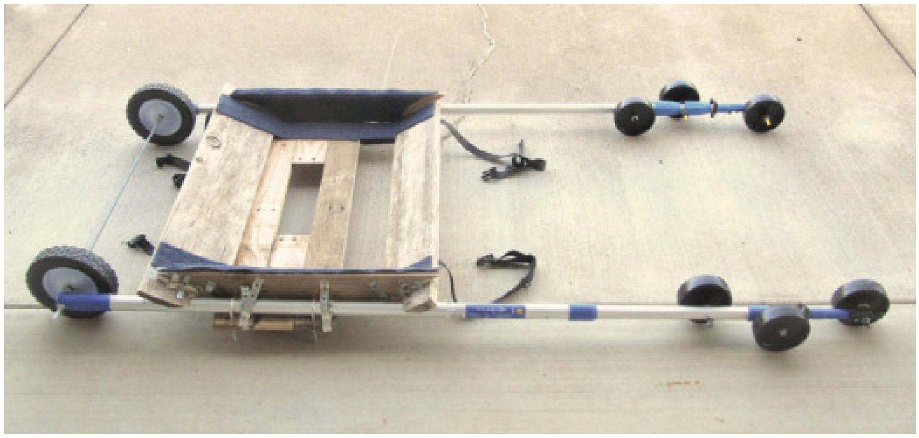
The Rampless Scope Lift

Load your scope without fear — or much effort.

MOST OWNERS OF large telescopes either have an observing site at home or have a set of ramps for loading the scope into their vehicle. Ramps, combined with long handles and wheels that bolt onto the rocker box, allow you to roll the scope's bulky bottom end like a wheelbarrow up into your ride.

The problem is, big scopes can be heavy, while SUVs and pickups can be pretty darned tall. Those ramps need to be long, and the person behind the wheelbarrow handles needs enough stamina and accurate aim to shove the scope all the way up in one smooth run. If not . . . well, I know a guy who lost control of his scope and woke up with a park ranger splashing cold water on his badly bruised face.

When Lauren Wingert (featured in my July 2021 & December 2022 columns) became the temporary custodian of Mel Bartels's 25-inch Zip Dob (*S&T:* Feb. 2019, p. 70), she knew that ramps would never work for her. So being a total gadget girl, she set out to design something that didn't require the strength of an ox nor the aim of William Tell.



▲ The Wheelie Lift Cart consists of two long poles with wheels on either end and a cradle to hold the telescope's mirror box.

She came up with what she calls the "Wheelie Lift Cart." It's basically a cradle for the folded-up mirror box with two long poles attached to the sides of the cradle. The poles have wheels at either end, with the cradle sitting close to one set of wheels. Lauren places the mirror box into the cradle, which is fairly easy while the cradle rests on the ground. She straps the mirror box in, then goes around to the long end of the handles and lifts them up to hip height, just as you would lift a wheelbarrow. And as with a wheelbarrow, the mechanical advantage of those long handles makes lifting the 23-kilogram (50-pound) mirror box easy.

The wheels on the short end of the rods allow Lauren to roll the scope to the back of her car, with the mirror box never getting more than a foot off the ground. When she gets to the car, she positions the lift cart with its long handles pointed at the open back end,

▲ The long handles and large wheels make rolling the cart easy.

▲ The long handles are easily lifted to the car's deck height. Ropes secured within the car prevent the cart from rolling back out.

▲ The cart and telescope fit snugly inside Lauren's car for transport.

ALL IMAGES COURTESY OF LAUREN WINGERT

sets it down, then turns around, lifts the handles, and pulls the rig forward a bit to rest on the back deck of the car.

She then clips restraint ropes attached to the interior of the car to the ends of the handles so the cart can't roll back out, goes around to the other end, and lifts the cart and mirror box by the short handles. This can be done with leg strength, preserving her back.

Then Lauren simply rolls the entire works into her car. Multiple wheels on the long poles make for a smooth ride even across a bumpy cargo deck. The rope restraint slackens as the cart rolls inward. She carefully measured the pole lengths to fit against the seat backs, leaving just enough room for the hatch to close. The ground ring and secondary cage nestle in between the long cart handles, and the truss poles go alongside.

When she gets to her observing site, Lauren simply reverses the procedure and rolls the scope to her setup spot. She positions the ground ring and flex rockers (yes, plural: the Zip Dob has two), transfers the mirror box from its cradle to the flex rockers, and completes the setup as with any truss scope.

The poles are lightweight painters' reach extension poles, which consist of three telescoping aluminum tubes inside one another. They're plenty strong for this application. The cradle is made of scrap palette wood, reinforced with metal strapping and padded with carpet. The ground wheels are seven inches in diameter to roll over rough terrain, while the deck wheels are five inches.

The Wheelie Lift Cart isn't for everybody. If you have a short cargo deck, the poles would have to be too short to bridge between the ground and the car at a comfortable angle. But if you have room for a ramp, you have room for Lauren's cart, and you won't have to roll a heavy telescope uphill anymore.

For more information, contact Lauren at **lauren@sneakpeekglass.com**.

■ Contributing Editor **JERRY OLTION** can still lift his scope into the car, but he definitely sees one of these in his future.

Which Way Is Up?

TELESCOPES ARE FANTASTIC TOOLS. They are opto-mechanical eye enhancements, enabling us to see extremely distant objects with increasing clarity. And the bigger a telescope's aperture is, the farther and fainter the objects it can reveal. Amazing!

But one of the most surprising discoveries every amateur makes when they start exploring the night sky with their first telescope is that the image in the eyepiece differs noticeably from what might be expected — star patterns appear upside down or even mirror-reversed. So, what's wrong?

Don't worry, nothing is amiss. This is how telescopes work. None of them produces a right-reading image (one that is oriented exactly as you see without the telescope). In fact, the lenses in your own eyes produce an inverted image on your retinas, and your brain does the work flipping it — which is why we see everything "upright." So why can't telescopes do the same?

Simply put, there is no need to correct the image at the eyepiece, for a couple of reasons. For one thing, there is no "up" in space. Your sense of direction is entirely based on your lifelong experience of living on a terrestrial sphere (Earth), and the flipped or upside-down view of celestial objects won't be a distraction at all.

Although there are corrective optics you can put in the light path to produce a truly right-reading view, these devices are optical compromises that absorb a little bit of light and can make the views slightly less sharp. When you're looking at a distant galaxy at the limit of detectability in your telescope, it's often most important to gather as much light as you can to even see the target object. So the orientation of the view is of little concern.

Still, understanding how different telescope designs orient an image will make it easier to relate what you see in your eyepiece to what's presented on your star maps. Star atlases don't come in mirror-reversed editions, so you'll need to flip the view in your head in order to star-hop to the nebula, galaxy, or double star you're intending to bag in the eyepiece. No matter the type of telescope, stars always move across the field from east to west.

Getting Oriented

The reason you see a reversed scene in your telescope has to do with the number of times the image is reflected before reaching your eye. An even number of reflections generates a right-reading, though upside-down, view, while an odd number produces a mirror image.

The optical configuration of a Newtonian reflector offers the biggest aperture for the least cost. A Newtonian first reflects the light from a parabolic primary mirror to a flat secondary mirror in order to redirect the light path out of the side of the tube, so that your head isn't obscuring the view. This results in an image that is typically upside down or even rotated at a more unnatural angle, depending on how the focuser is oriented. In fact, the image will only be level if the focuser is pointing straight up from the telescope tube and you are positioned behind the primary mirror. This is one reason Newtonians are not recommended for terrestrial use, such as bird watching. Fortunately, when looking at the night sky it's just a matter of rotating your star map to match the view in the eyepiece.

ALL IMAGES COURTESY OF THE AUTHOR

GETTING YOUR BEARINGS The view through the most common telescope designs adds a level of confusion due to the nature of optics. This image of the Moon compares the terrestrial view (near right) with the view through Newtonian reflectors, refractors, and Cassegrain telescopes without a star diagonal (middle). The image appears upright but mirror-reversed when adding a 90° star diagonal to a refractor or Cassegrain (far right).

Refractors and catadioptric telescopes (Schmidt-Cassegrains, Maksutov-Cassegrains, and classical Cassegrains) each produce an upside-down image when viewed straight through. Refractors don't reflect the light at all — they're basically lenses at either end of a tube — and perform much like your eyes do. Cassegrains, most of which use a combination of mirrors and lenses, reflect incoming light twice (an even number of times). But unlike Newtonians, Cassegrains reflect the light through a hole in the primary mirror and so produce an easily accessible though upside-down view just like a refractor does.

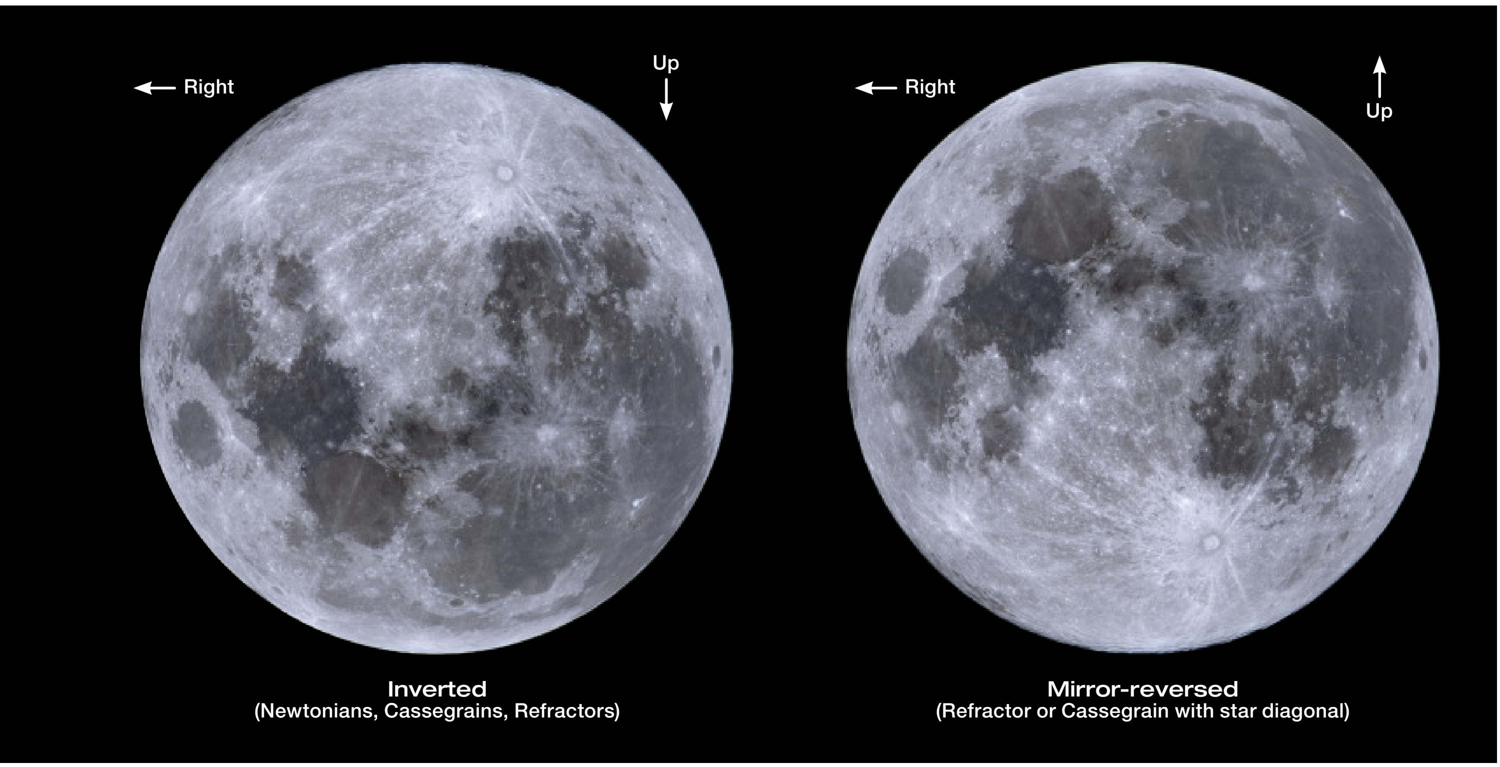
Of course, viewing the sky straight through these instruments can be uncomfortable at most angles, so adding the single reflection from a 90° star diagonal (a mirror or prism positioned in the optical path) will relieve the kink in your neck and flip the view so it's at least corrected right-side up — but it will now be mirror-reversed. When equipped with a star diagonal, refractors and Cassegrains make excellent instruments for terrestrial use.

An option for observers who want to maximize the versatility of their telescope is to add an erecting prism that creates a right-reading orientation. These devices reflect the incoming light twice to produce a right-reading image in the eyepiece. These are great accessories for daytime activities. Some companies even offer image-correcting eyepieces, which perform the same feat.

◀ **ADDING A STAR DIAGONAL** Viewing straight through a refractor (or Cassegrain) produces an inverted view but is uncomfortable for targets high in the sky. Inserting a 90° star diagonal makes the angle more comfortable, though the view then appears mirror reversed.

There is a price for this, though. As noted earlier, each of these additional reflections loses some of the light and sharpness, which can make the difference between seeing your target or not. Some erecting-prism designs also introduce a diffraction spike to bright points in the view (think stars and planets).

Knowing which way the image is oriented in your telescope makes it much easier to track down the objects you want to see. The views through Newtonians are easiest to compare to a chart or photograph. Refractors and Cassegrains are most convenient to use with a star diagonal, though that complicates comparing what you see in the eyepiece with maps or pictures. Still, you might find the advantage of a comfortable viewing angle to be more important than the ability to easily use star charts — especially since software charts allow you to match the orientation of your specific telescope. ■



Inverted
(Newtonians, Cassegrains, Refractors)

Mirror-reversed
(Refractor or Cassegrain with star diagonal)

VENUS MEETS THE DAUGHTERS OF ATLAS

Osama Fathi

On April 14th, brilliant Venus shone between the Hyades open cluster (Caldwell 41) at upper left and M45, the Pleiades (middle), with Mercury peeking just above the mountainous horizon of the Black Desert in Egypt. The streak of reddish nebulosity at top right is NGC 1499, also known as the California Nebula.

DETAILS: *Nikon Z6 camera with a 28-to-70-mm lens. Stack of 13 exposures recorded at both ISO 800 and 3200, f/4.*

◁ A CUP OF TOTALITY
Dan Hurley

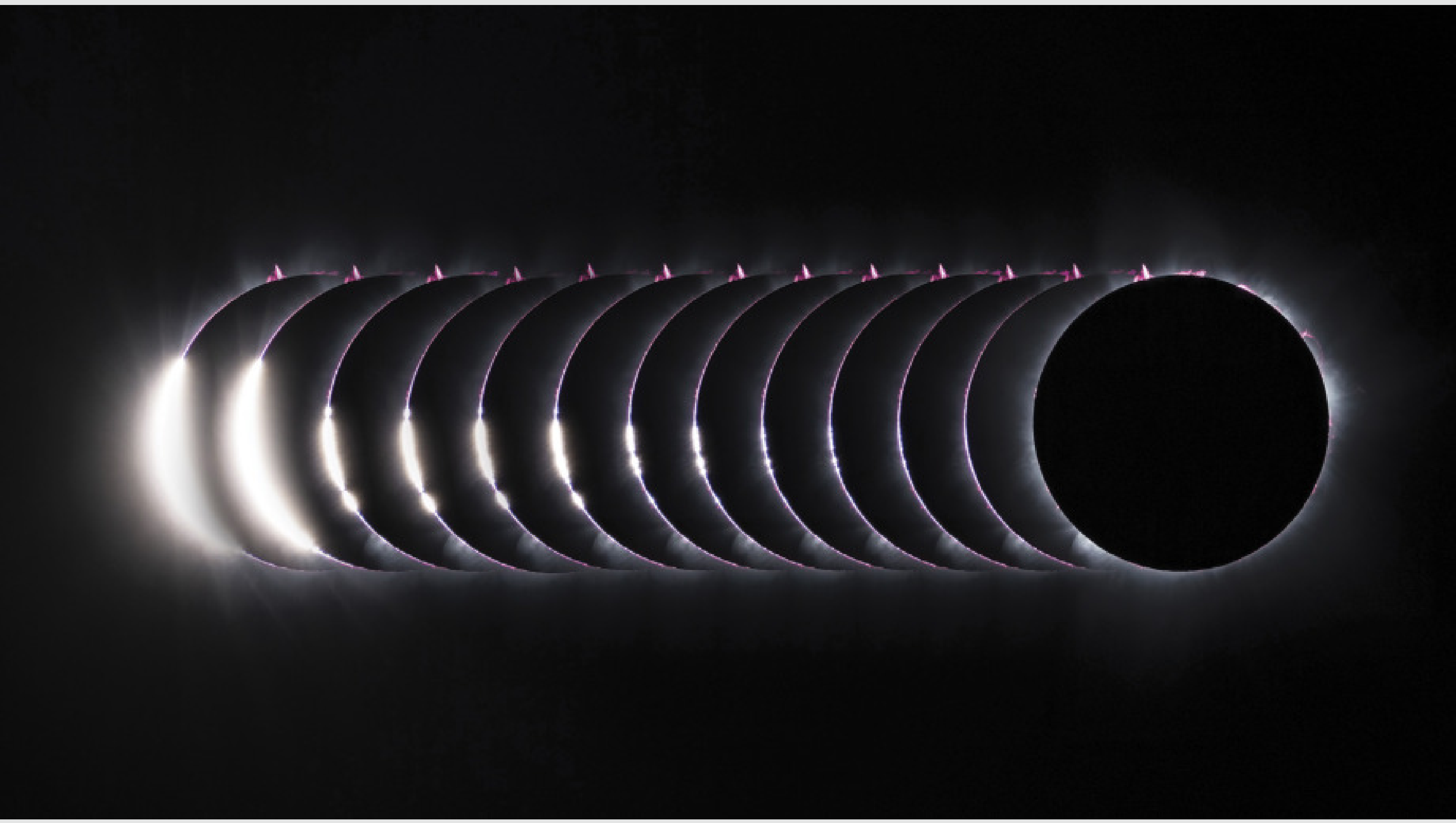
We've seen many creative solar eclipse images, but this is a first for us. Umbraphile Dan Hurley captured totality reflected in his coffee with his iPhone during the hybrid solar eclipse over Exmouth, Australia, on April 20th. In the reflection, the Moon appears as a small, dark speck surrounded by the Sun's bright corona.

DETAILS: *Apple iPhone SE (2nd generation). Total exposure: 1⁄25 second at f/1.8, ISO 640.*

▽ BAILY'S BEADS
Chirag Upreti

This composite image shows the moments leading up to totality during the hybrid solar eclipse over South Lefroy Bay, Australia, on April 20, 2023. Several bright prominences are seen ringing nearly the entire lunar limb.

DETAILS: *Sony α7R III camera with a 200-to-600-mm zoom lens. Composite of 13 exposures, each 1⁄2000 second long at f/9.5, ISO 320.*



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Ad Index

More Better Gooder

How the author succumbed to, then conquered, aperture creep — with the most satisfying result.

ONE THING HAS BEEN a constant for me in amateur astronomy almost since the beginning: the quest for what a Navy Chief of my acquaintance called "more better gooder." Better astronomy gear — that is, better telescopes, eyepieces, cameras, all of it.

My fascination with observing began with my first telescope, a 3-inch Tasco reflector. It opened the heavens for me. I remember how good the Moon looked and how exciting it was to dip a toe in the great, dark ocean of the deep sky.

Alas, that initial enthusiasm didn't last. I began to feel dissatisfied with the way deep-sky objects looked in my scope. They weren't a bit like those I saw in the astronomy books that my mother, a school librarian, brought home for me. Messier 13, the Great Globular Cluster in Hercules that the authors enthused over, was a dim blob. I needed more — *more telescope*. A 6-inch, maybe. Surely one of those would show me M13's countless tiny suns.

Thus began my enduring obsession with astronomy gear: the ever-bigger scope or ever costlier eyepiece that would *finally* allow me to see what I really wanted to see. I enjoyed a succession of fancy toys over the decades, and some amazing views, but I still wasn't content. I worried about what I couldn't see instead of enjoying what I could.

And so it went, until one night a few years after retirement when I realized I was afraid to set up my big Schmidt-Cassegrain. The last time I'd tried to get it onto its huge equatorial mount, I'd nearly dropped it. My fine array of astro stuff was beginning to be too much. Plus, I thought, I really shouldn't leave all that equipment for my wife and family to deal with when I make the final trip into the ether. I held onto my smaller refractors and 8-inch SCT, and everything else went to new homes.

I figured that was the end of my astronomical journey. I was pretty sure I'd become that somewhat sad specimen, the armchair astronomer. I sat inside and watched television as the stars wheeled their ancient courses overhead night after night.

Then, one evening, I decided I wanted to look at something with a telescope. No, I *needed* to look at something. Out came my 80-mm refractor. I could look at the Moon, I thought. That would be pleasing, and the tiny telescope would at least show me *that*.

Did it ever.

Fortunately, I didn't stop there. Over I went to the Great Globular Cluster. Wait . . . was I seeing a few stars resolved? It wasn't as "good" as it was in my big scopes, but it was beautiful, nonetheless. Memories of all the fun I'd had with tiny telescopes half a century ago came rushing back.

Now I delight in what I *can* see. The Moon is every bit as remarkable as she was the first time I admired her shining face. Saturn's rings are as astounding as ever. And my telescope still transports me across dark light-years to bathe in the wisps of M42, the Orion Nebula. I've learned to see again, to stop worrying and instead delight in what my wonderful telescope shows me.

■ After five decades as an enthusiastic amateur astronomer, Contributing Editor **ROD MOLLISE** continues to admire the night sky at every opportunity.

LEAH TISCIONE / *S&T*


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